Soil Moisture Active and Passive (SMAP) Mission

Science Calibration and Validation Plan

SMAP Science Document. No: 014

Version: 1.0 (Preliminary Release)

Authors:

Tom Jackson
United States Department of Agriculture

John Kimball
University of Montana

Andreas Colliander
Jet Propulsion Laboratory, California Institute of Technology

Eni Njoku
Jet Propulsion Laboratory, California Institute of Technology

Contents

1 INTRODUCTION AND SCOPE

1.1 Purpose

This document describes the plan for calibrating and validating Level 1 through Level 4 science data products of the Soil Moisture Active and Passive (SMAP) Mission. The SMAP Calibration and Validation (Cal/Val) Plan is the basis for implementation of the detailed set of calibration and validation activities that take place during the SMAP mission lifetime.

1.2 Scope and Objectives

SMAP is one of four missions recommended by the National Research Council's Committee on Earth Science and Applications from Space for launch in the 2010 to 2013 period [1]. SMAP will provide global measurements of surface soil moisture and freeze/thaw state. The high accuracy, resolution, and global coverage provided by SMAP measurements will serve science and applications disciplines that include hydrology, climate, and carbon cycle, and the meteorological, agricultural, environmental, and ecological applications communities.

SMAP mission science requirements are contained in the Level 1 science requirements document: Science Requirements and Mission Success Criteria (SRMSC) [2]. Included in this document are requirements for accuracy, spatial resolution, and temporal revisit for the soil moisture and freeze/thaw measurements, and mission duration, for both baseline and minimum missions (Section 2.2). Also stated in the SRMSC is the requirement that a Calibration and Validation Plan be developed and implemented to minimize and assess random errors and spatial and temporal biases in the soil moisture and freeze/thaw estimates, and that the SMAP validation program shall demonstrate that SMAP retrievals of soil moisture and freeze/thaw state meet the stated science requirements.

The SMAP Cal/Val Plan includes pre-launch and post-launch activities starting in Phase A and continuing after launch and commissioning through the end of the mission (Phase E). The scope of the Cal/Val plan is the set of activities that enable the pre-and post-launch Cal/Val objectives to be met.

- The Pre-Launch objectives of the Cal/Val program are to:
  - Acquire and process data with which to calibrate, test, and improve models and algorithms used for retrieving SMAP science data products;
  - Develop and test the infrastructure and protocols for post-launch validation; this includes establishing an in situ observation strategy for the post-launch phase.
- The Post-Launch objectives of the Cal/Val program are to:
  - Verify and improve the performance of the science algorithms;
  - Validate the accuracy of the science data products.

1.3 Roles and Responsibilities

The SMAP Cal/Val Plan is developed and implemented by the SMAP Cal/Val Team, which includes members of the Science Definition Team (SDT), the SDT Cal/Val Working Group, and members of the Project Science and Science Data System staff at JPL and GSFC. The SMAP Cal/Val Plan will be developed taking into consideration a broad range of inputs and contributions from the U.S. and international communities, including Cal/Val plans of other microwave remote sensing missions related to the hydrology and ecology disciplines.

1.4 Document Overview

Section 1 provides introductory information on scope and contents.
Section 2 provides an overview of SMAP science objectives, data products, and mission operations.
Section 3 provides an overview of methodology relevant to the SMAP calibration and validation planning.
Section 4 presents the requirements for the Cal/Val activities identified by the science products and their ATBDs.
Section 5 describes details of planned pre-launch SMAP Cal/Val activities.
Section 6 describes details of planned post-launch SMAP Cal/Val activities.
Section 7 describes international Cal/Val coordination, including data availability, access, and exchange.
Section 8 describes the SMAP SDT Cal/Val Working Group.
Section 9 provides a list of references and sites for further information.

1.5 Cal/Val Program Deliverables

The deliverables of SMAP Cal/Val Program fall in the following six categories:

(1) SMAP Science Cal/Val Plan document;
(2) Implementation plans for identified pre- and post-launch field campaigns;
(3) Reports documenting results, archival, and analyses of pre-launch field campaigns and data acquisitions;
(4) Beta Release and Validation report for L1 data accompanying archived data (at IOC plus three and six months, respectively);
(5) Beta Release and Validation report for L2-L3 data accompanying archived data (at IOC plus three and twelve months, respectively);
(6) Validation report for L4 data (accompanying archived data at post-IOC plus twelve months).

2 SCIENCE AND MISSION OVERVIEW

2.1 Science Objectives

SMAP is a spaceborne Earth observation mission designed to measure surface soil moisture and freeze/thaw state (together termed the hydrosphere state). SMAP hydrosphere state measurements will yield a data set that will enable science and applications users to:

- Understand processes that link the terrestrial water, energy and carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Enhance weather and climate forecast skill
- Develop improved flood prediction and drought monitoring capability

The SMAP mission is designed to validate a space-based measurement approach that could be used for future systematic hydrosphere state monitoring missions.

2.2 Science Requirements

The SMAP Level 1 science requirements are the basis for achieving the science objectives of the mission. These requirements are described in the Level 1 Science Requirements and Mission Success Criteria (SRMSC) document [2]. The relevant Level 1 science requirements are listed in Appendix A.

2.2.1 Measurements

The Level 1 'Baseline' and 'Minimum' SMAP science requirements are summarized in Table 2-1. The requirements are derived from science assessments, reviewed in a series of NASA and community workshops [3]. The requirements rationales are summarized in SMAP Science Document [4]. Note that for practical reasons the 10 km resolution requirement was translated to 9 km grid resolution for Level 2 through L4 soil moisture products.

The requirements listed in Table 2-1 are to be met over land areas identified by the regions shown in Figure 2-1 and Figure 2-2.

Table 2-1. SMAP Level 1 Science Requirements Summary

Requirement	Baseline Mission		Minimum Mission	
	Soil Moisture	Freeze/ Thaw	Soil Moisture	Freeze/ Thaw
Resolution	10 km	3 km	10 km	10 km
Refresh Rate	3 days	2 days(1)	3 days	3 days(1)
Accuracy	0.04 $m^3/m^{3(2)}$	80%(3)	0.06 $m^3/m^{3(2)}$	70%(3)
Duration	36 months		18 months	

(1) North of 45°N Latitude
(2) volumetric water content, standard deviation (1-sigma)
(3) % classification accuracy (binary: Freeze or Thaw)

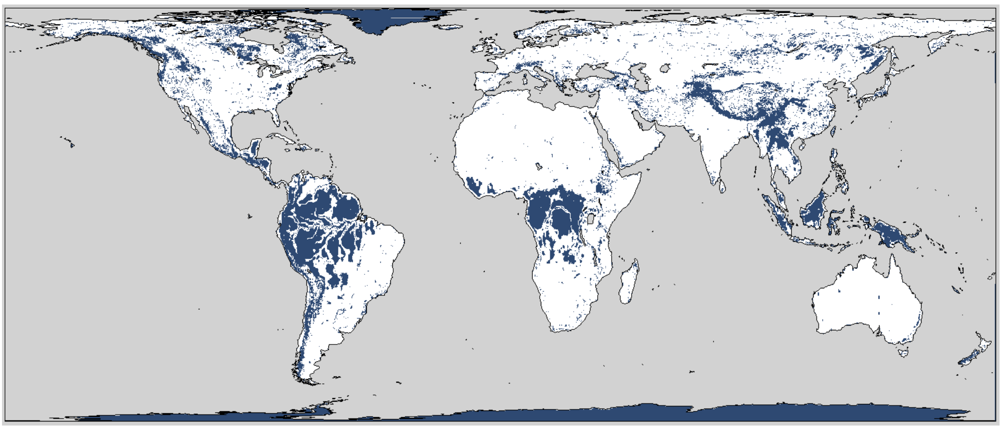


Figure 2-1. Regions of coverage (white areas) where soil moisture requirements are to be met.

Figure 2-2. Regions of coverage (white areas) where freeze/thaw requirements are to be met.

2.2.2 Data Delivery

SMAP requirements are that the SMAP project shall begin the first release of validated Level 0 and Level 1 instrument data products (Section 2.4) to the public no later than six months after the end of the In-Orbit Check-out (IOC) phase (Section 2.6). Before releasing the first version of the validated data, beta and provisional data product versions will be released.

Similarly, no later than twelve months after the end of the IOC phase the SMAP project shall begin the first release of validated Level 2 to Level 4 geophysical data products to the public. Before releasing the first version of the validated data, beta and provisional data product versions will be released. The final processed mission data set shall be available for delivery to the public within one month after the end of the mission (Level 3 Mission System Requirements).

2.3 Mission Implementation Approach

2.3.1 Requirements Flow-Down

The SMAP Level 1 requirements are traced to Level 2 science requirements as shown in Table 2-2. A list of the relevant Level 2 science requirements is provided in Appendix B.

Table 2-2. SMAP Requirements Traceability Matrix

Science Objectives	Scientific Measurement Requirements	Instrument Functional Requirements	Mission Functional Requirements
Understand processes that link the terrestrial water, energy and carbon cycles; Estimate global water and energy fluxes at the land surface; Quantify net carbon flux in boreal landscapes; Enhance weather and climate forecast skill; Develop improved flood prediction and drought monitoring capability.	<u>Soil Moisture:</u> ~0.04 m^3/m^3 accuracy in top 5 cm for vegetation water content < 5 kg m^{-2}; Hydrometeorology at 10 km; Hydroclimatology at 40 km	<u>L-Band Radiometer:</u> Polarization: V, H, U; Resolution: 40 km; Relative accuracy*: 1.5 K <u>L-Band Radar:</u> Polarization: VV, HH, HV; Resolution: 10 km; Relative accuracy*: 0.5 dB for VV and HH Constant incidence angle** between 35° and 50°	Data Center data archiving and distribution. Validation program. Integration of data products into multisource land data assimilation.
	<u>Freeze/Thaw State:</u> Capture freeze/thaw state transitions in integrated vegetation-soil continuum with two-day precision, at the spatial scale of landscape variability (3 km).	<u>L-Band Radar:</u> Polarization: HH; Resolution: 3 km; Relative accuracy*: 0.7 dB (1 dB per channel if 2 channels are used); Constant incidence angle** between 35° and 50°	
	Sample diurnal cycle at consistent time of day Global, 3-4 day revisit; Boreal, 2 day revisit	Swath Width: 1000 km Minimize Faraday rotation (degradation factor at L-band)	Orbit: 670 km, circular, polar, sun-synchronous, ~6am/pm equator crossing
	Observation over a minimum of three annual cycles	Minimum three-year mission life	Three year baseline mission***

* Includes precision and calibration stability, and antenna effects
** Defined without regard to local topographic variation
*** After completion of the in-orbit check-out phase

2.3.2 Measurement Approach

The SMAP measurement configuration is shown in Figure 2-3. Key features of the system are provided in Table 2-3.

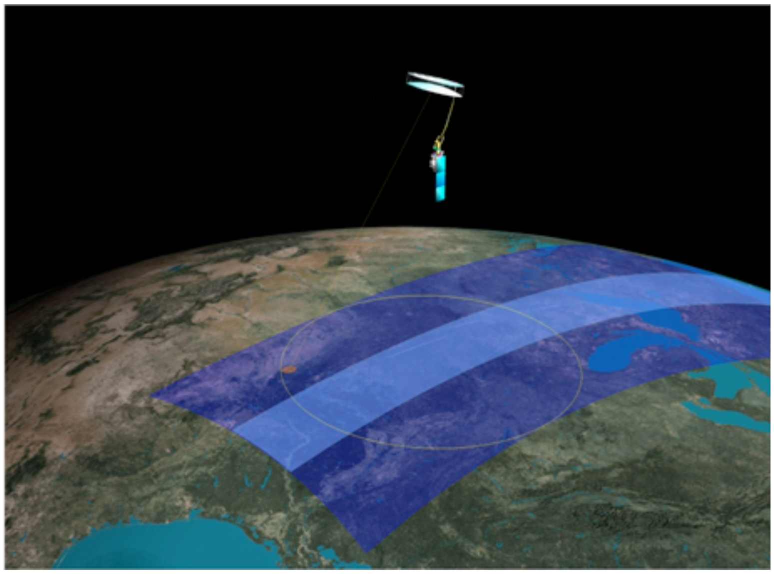


Figure 2-3. SMAP measurement system indicating conical scan and wide swath.

Table 2-3. Key Measurement System Characteristics

Radar:
- L-band (1.26 GHz); HH, VV, HV
- High resolution, moderate accuracy soil moisture
- Freeze/thaw state detection
- 3 km SAR resolution
- 30 x 6 km real-aperture resolution

Radiometer:
- L-band (1.4 GHz); H, V, U
- Moderate resolution, high accuracy soil moisture
- 40 km resolution

Shared Antenna:
- 6-m diameter deployable mesh antenna
- Conical scan at 14.6 rpm
- Constant incidence angle of 40 degrees

Orbit:
- Sun-synchronous, 6 am/pm orbit
- 670 km altitude
- 1000 km-wide swath
- Swath and orbit enable 2-3 day revisit

Mission Operations:
- 3-year baseline mission

2.4 Science Data Products

The SMAP science requirements will be met by generating the data products listed in Table 2-4. The data products will be generated by the SMAP Science Data System (SDS) (Section 2.5). Science software for the data products will be developed using a set of algorithms described in the Algorithm Theoretical Basis Documents (ATBDs). There will be one ATBD for each science data product.

Table 2-4. List of SMAP Science Data Products.

Data Product Short Name	Short Description	Spatial Resolution	Grid Spacing	Latency*
L1A_Radar	Radar raw data in time order	NA	NA	12 hours
L1A_Radiometer	Radiometer raw data in time order	NA	NA	12 hours
L1B_S0_LoRes	Low resolution radar σ_o in time order	5x30 km	NA	12 hours
L1B_TB	Radiometer T_B in time order	40 km	NA	12 hours
L1C_S0_HiRes	High resolution radar σ_o (half orbit, gridded)	1x1 km to 1x30 km	1 km	12 hours
L1C_TB	Radiometer T_B (half orbit, gridded)	40 km	36 km	12 hours
L2_SM_A**	Soil moisture (radar, half orbit)	3 km	3 km	24 hours
L2_SM_P	Soil moisture (radiometer, half orbit)	40 km	36 km	24 hours
L2_SM_A/P	Soil moisture (radar/radiometer, half orbit)	9 km	9 km	24 hours
L3_F/T_A	Freeze/thaw state (radar, daily composite)	3 km	3 km	36 hours
L3_SM_A**	Soil moisture (radar, daily composite)	3 km	3 km	36 hours
L3_SM_P	Soil moisture (radiometer, daily composite)	40 km	36 km	36 hours
L3_SM_A/P	Soil moisture (radar/radiometer, daily composite)	9 km	9 km	36 hours
L4_SM	Soil moisture (surface & root zone)	9 km	9 km	7 days
L4_C	Carbon net ecosystem exchange (NEE)	9 km	1 km	14 days

* SMAP L2 science requirements. Mean latency under normal operating conditions. The SMAP project will make a best effort to reduce these latencies

** Research products (archival at discretion of project)

Implementation of this Cal/Val Plan will provide documented assessments of the random errors and regional biases in the science data products, and verification that the accuracies of the soil moisture and freeze/thaw estimates of these products meet the SMAP mission science requirements and objectives.

2.5 Science Data System (SDS)

The functional architecture of the SMAP Science Data System is shown in Figure 2-4. The SDS supports Cal/Val, by providing analysis tools that enable generation and assessment of quality indicators from specified products and by accommodating special data processing needs. External ancillary data including Cal/Val data from field campaigns, in situ networks, and special target data sets provided by the Science Team are ingested into the Cal/Val Database on SDS Testbed (see Section 5.4.2) and SDS Life-of-Mission (LOM) storage. Initially, the SDS science product data processing is done with the prelaunch parameter sets and algorithms. Derivation of new sets of processing parameters and their evaluation are performed using the SDS Algorithm Testbed. The

SDS supports both the Cal/Val phase and the routine observations phase (see Section 2.6), which involve extended monitoring and data evaluations through the life of the mission.

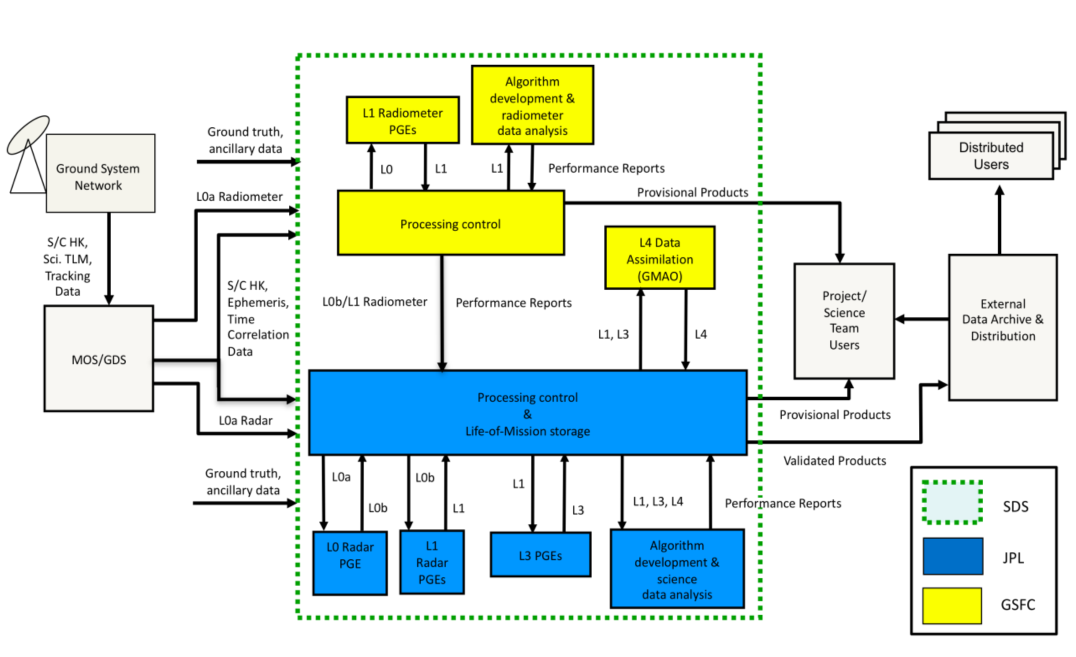


Figure 2-4. SMAP Science Data System Architecture

2.6 Mission Operations

The SMAP *Science Observation Phase (SOP)* follows the 90-day *In-Orbit Check-out (IOC) phase*, and extends for the duration of the science mission (baseline three years). During the SOP, routine global data coverage and low-loss data delivery are provided to meet the primary science mission objectives.

The first part of the SOP is the *Calibration and Validation (Cal/Val) Phase*, which extends for twelve months after IOC and includes intensive sensor calibration, special field campaigns, data acquisitions, intensive analysis and performance evaluation of the science algorithms and data product quality.

The *Routine Observations Phase* follows the Cal/Val Phase, during which routine science data processing and data quality assessments will be performed. Continued Cal/Val activities will occur during this phase but are focused primarily on monitoring and fine-tuning the quality of the science data products. This may lead to Science Team recommendations for algorithm upgrades and reprocessing if they are necessary and within the available mission resources.

2.6.1 Calibration and Validation (Cal/Val) Phase

The first part of the Science Observation Phase will be devoted to a period of Calibration and Validation of the L0-L4 data products.

During the Cal/Val phase, the Science Team evaluates the accuracy and quality of the data products generated by the SDS, following the protocols stated in the Cal/Val plan. The L0 and L1 product Cal/Val will include verifying that the geolocated brightness temperatures and radar backscatter values align to known terrestrial features such as coastlines, islands and other significant topographical features. Natural targets with relatively stable microwave and known characteristics (such as cold sky, tropical forest, and ice sheets) will be used to assess the precision and calibration bias stability of the instrument. This activity validates instrument pointing, radiometer and radar operation, and the L0 and L1 data processing. During L0-L1 Cal/Val, terrestrial radio frequency interference (RFI) in the instrument data will be evaluated to confirm the effectiveness of both flight system and ground processing mitigations. The L2-L4 Cal/Val will include validation using terrestrial in situ sensor data, airborne microwave sensor data, special field campaign in situ data collections, comparisons with other mission sensor data, such as the European Space Agency's (ESA's) Soil Moisture and Ocean Salinity (SMOS) mission and the NASA Aquarius mission, and numerical model output data.

SMAP is required to begin delivering calibrated and validated L1 science products to a NASA-designated and funded Data Center within six months after the completion of IOC. The beta release of L1 data products is to be delivered 3 months after IOC. It is TBD whether a provisional version of L1 data products will be released. Validated L2-L4 science products are required to be available for delivery to the Data Center within twelve months after the IOC. The beta release of L2 data products is to be delivered 3 months after IOC. It is TBD whether a provisional version of L2-L4 data products will be released. At the end of the L0-L1 and L2-L4 calibration activities, the previously collected data will be reprocessed using the calibrated/validated algorithms, so that they become part of a consistently processed total mission data set. The Data Center is responsible for permanent archiving and public distribution of the SMAP data products.

2.6.2 Routine Observations Phase

During the Routine Observations Phase, the instrument and science data product performances are regularly monitored for long-term trend analysis and re-calibration. The trend analyses will be based on comparisons of the science data products against routinely available data from in situ networks and calibration monitoring sites. Derivation of new sets of processing parameters and algorithm upgrades will be done and implemented on the SDS as directed by the Science Team. The total number of supported reprocessing of the mission data is three.

3 OVERVIEW OF VALIDATION METHODOLOGY

3.1 Background

In developing the Cal/Val plan for SMAP there are precedents and experiences that can be utilized. The Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) [5] has established standards that may be used as a starting point for SMAP. The Land Products Sub-Group [6] has expressed the perspective that "A common approach to validation would encourage widespread use of validation data, and thus help toward standardized approaches to global product validation. With the high cost of in situ data collection, the potential benefits from international cooperation are considerable and obvious".

Cal/Val has become synonymous in the context of remote sensing with the suite of processing algorithms that convert raw data into accurate and useful geophysical or biophysical quantities that are verified to be self-consistent. Another activity that falls in the gray area is vicarious calibration, which refers to techniques that make use of natural or artificial sites on the surface of the Earth for the post-launch calibration of sensors.

A useful reference in developing a validation plan is the CEOS Hierarchy of Validation [6]:

- Stage 1: Product accuracy has been estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program efforts.
- Stage 2: Product accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts.
- Stage 3: Product accuracy has been assessed, and the uncertainties in the product well-established via independent measurements made in a systematic and statistically robust way that represents global conditions

A validation program would be expected to transition through these stages over the mission life span.

The SMAP mission is linked by common L-band frequency with the SMOS, Aquarius, ALOS-2 and SAOCOM missions, and by its soil moisture products with the GCOM-W and NPOESS (or its successors) missions (operating at C-band and higher frequencies). All of these missions could be generating soil moisture products at the same time; therefore, SMAP will attempt to cooperate in their validation activities to improve the efficiency and robustness of its Cal/Val.

3.2 Definitions

In order for the Calibration/Validation Plan to effectively address the mission requirements, a unified definition base has to be developed. The SMAP Cal/Val Plan uses the same source of terms and definitions as the SMAP Level 1 and Level 2 requirements. These are documented in the SMAP Science Terms and Definitions document [7], where Calibration and Validation are defined as follows:

- *Calibration*: The set of operations that establish, under specified conditions, the relationship between sets of values or quantities indicated by a measuring instrument or measuring system and the corresponding values realized by standards.

- *Validation:* The process of assessing by independent means the quality of the data products derived from the system outputs

The L2 product requirements (see Appendix B) are interpreted in [8] for computing the validation quality metric.

Before releasing validated products the mission is required to release beta products, and possibly provisional products (see Section 2.6.1). The maturity of the products in beta release is defined as follows:

- Early release used to gain familiarity with data formats.
- Intended as a test bed to discover and correct errors.
- Minimally validated and still may contain significant errors
- General research community is encouraged to participate in the QA and validation, but need to be aware that product validation and QA are ongoing.
- Parameter may be used in publications as long as beta quality is indicated by the authors. Drawing quantitative scientific conclusions is discouraged. Users are urged to contact science team representatives prior to use of the data in publications, and to recommend members of the instrument teams as reviewers
- The estimated uncertainties will be documented.
- May be replaced in the archive when an upgraded (provisional or validated) product becomes available.

The product maturity of the provisional release is defined as:

- Incremental improvements are ongoing. Obvious artifacts or errors observed in beta product have been identified and either minimized or documented.
- General research community is encouraged to participate in the QA and validation, but need to be aware that product validation and QA are ongoing.
- Product may be used in publications as long as provisional quality is indicated by the authors. Users are urged to contact science team representatives prior to use of the data in publications, and to recommend members of the instrument teams as reviewers.
- The estimated uncertainties will be documented.
- Will be replaced in the archive when an upgraded (validated) product becomes available.

3.3 Validation Methods, Resources and Data Availability

3.3.1 In Situ Networks

In situ soil moisture, surface and air temperature, and land surface characteristics observations will be important in validating science products from the SMAP mission. These data will also be valuable throughout the development phase of the mission to support field campaigns, modeling, and synergistic studies using AMSR, PALSAR, SMOS, and Aquarius. Existing resources that are expected to continue through the life span of SMAP in orbit (2014 through 2017) are highly desirable.

An ideal in situ soil moisture resource would include a verified (as described above) surface layer observation (5 cm soil depth), the 0-100 cm profile, a spatial domain approximately the size of the retrieval footprint (3, 10, and 40 km) with replication, numerous domains in a variety of climate/geographic regions, real time availability on a public server, and additional meteorological measurements.

An ideal freeze/thaw resource would include similar attributes as a soil moisture resource, but with additional measurements of reference (2 m height) air temperature and vegetation (stem and canopy) temperature, high temporal fidelity (daily or better) sampling and representation over the observed range of climate, terrain, land cover and vegetation biomass conditions.

None of the available resources described here meet all these requirements, especially as stand-alone networks. However, if international cooperation and standardization can be achieved through activities, such as the ISMWG and GEO, it is possible that a good approximation of a global soil moisture network can be compiled. Even if this can be accomplished there will be gaps in coverage, which will be addressed by SMAP.

Ongoing Cal/Val efforts and in situ data acquisitions of other missions (AMSR and SMOS) will benefit the SMAP soil moisture and freeze/thaw Cal/Val effort. The AMSR missions (NASA and JAXA) have established validation networks in 2002 that are expected to continue through the time period of the GCOM-W mission (2012+). The SMOS Cal/Val program has supported several primary validation sites (Australia, Germany and Spain) and will be engaging many other groups during its validation program. In addition, SMOS (as well as the ISMWG and GEO) are attempting to establish a data archive of these data [9]. SMAP plans to participate in this activity. It will be of value to continue these efforts beyond the SMOS life span and into the SMAP mission period.

In addition to AMSR, SMOS, GCOM-W and other synergistic mission activities, there are Cal/Val resources in Russia, the Former Soviet Union (FSU) countries, China, and India that may be of value and efforts are ongoing to establish liaisons. New networks are being initiated (Western Africa and South Africa) that could be available in the future. However, there are major land regions (especially South America) where data sharing and infrastructure needs to be established. It is anticipated that through efforts underway related to Aquarius and SAOCOM that Argentina will establish in situ resources.

For soil moisture, a significant effort has been initiated called the International Soil Moisture Network (ISMN) [9]. The ISMN is an international cooperation to establish and maintain a global in-situ soil moisture database. The purpose of establishing this database is to provide the geoscientific community with a resource for validating and improving global satellite observations and land surface models. This international initiative is coordinated by the Global Energy and Water Cycle Experiment (GEWEX) in cooperation with the Group of Earth Observation (GEO) and the Committee on Earth Observation Satellites (CEOS). The International Soil Moisture Network has been made possible through the voluntary contributions of scientists and networks from around the world. The International Soil Moisture Network is operated in cooperation with the Global Soil Moisture Databank of the Rutgers University. Initial funding was provided by ESA in support of the SMOS mission. The ISMN is being populated at present and should mature over the next few years. The SMAP Cal/Val activities will include collaboration with the ISMN.

A preliminary summary of relevant in situ resources is presented in Table 3-1 and Figure 3-1 through Figure 3-4 present maps of some of the networks. Figure 3-1 shows the SCAN (blue dots), USCRN (yellow dots) and Oklahoma Mesonet (red dots) network, and some global and Australian measurement sites (red dots outside USA). The panels on top and underneath of the world map depict examples of dense measurement networks in USA and in Australia. Figure 3-2 shows the global network of biophysical monitoring sites, including in situ meteorological observations from World Meteorological Organization (WMO) weather stations, tower eddy covariance based CO_2, H_2O and energy flux measurements from FLUXNET sites, snow cover measurements from NRCS SNOTEL sites and landscape temperature profile measurements from Alaska Ecological Transect (ALECTRA) sites. These observation networks are limited in their ability for direct comparison and validation of satellite remote sensing retrievals, due to spatial heterogeneity in soil moisture and temperature conditions, and scale differences between in situ measurements and the sensor field-of-view. The data from this network (especially from relatively well equipped sites with broad spatial representation and more versatile sets of parameters) can be used as drivers of physical models for computation and spatial and temporal extrapolation of variables consistent with the resolution and attributes of the satellite products. Figure 3-3 shows the WMO in situ sites in North-America and highlights the Arkansas Red River Basin region which has been used for several simulation and model based (OSSE) experiments as a test case. Figure 3-2 and Figure 3-3 show also the FLUXNET and SNOTEL networks, measuring land-atmosphere water, energy and carbon fluxes and snow properties. Figure 3-4 is zoomed to show the ALECTRA network (yellow dots) in Alaska with FLUXNET, SNOTEL, SCAN and WMO sites. Additional details are under development.

At first glance Table 3-1 might indicate that there are a substantial number of in situ soil moisture resources available for validation. However, there are numerous issues that need to be addressed if these data are to be of value to SMAP validation:

- Details need to be collected and contacts established for each network. This includes expansions beyond the list provided here.
- Data distribution policies of each network should be reviewed and mechanisms for cooperation established. Data latency needs to be considered.
- The sparse networks consist of widely scattered points that require a scaling analysis if they are to be used to validate a satellite footprint.
- Verification and temporal stability analysis is needed of all footprint scale networks (i.e. Oklahoma Mesonet).
- Establishing or identifying infrastructure in under-represented regions (i.e. South America and Africa).
- Cooperation with the validation programs and archives of other satellite programs should be established and plans initiated for using these resources during SMAP pre- and post-launch activities.
- Consideration should be given to the roles of emerging networks such as COSMOS and GPS-based technologies.

Chapters 5 and 6 detail the plan for pre- and post-launch cal/val activities and address all these issues.

Table 3-1. Summary of possible Cal/Val Resource Networks (name of the network, the network coverage region, number of sites in the networks, whether the network is part of the International Soil Moisture Network (ISMN) database [9], and the website of the network).

Network Name	Country or Region	No. Sites	ISMN	Website or Other Reference
WMO global surface weather station network	Global	9000+		http://www.ncdc.noaa.gov/cgi-bin/res40.pl
Alaska Ecological Transect (ALECTRA)	Alaska	9		kyle.mcdonald@jpl.nasa.gov
FLUXNET	Global	500+		http://www.fluxnet.ornl.gov/fluxnet/index.cfm
Coordinated Energy and Water Cycle Observations Project (CEOP)	Global	13		http://www.ceop.net/
Chinese Ecosystem Research Network (CERN)	China	31		http://www.cern.ac.cn/0index/index.asp
Soil Climate Analysis Network (SCAN)	USA+	141		http://www.wcc.nrcs.usda.gov/scan/
Climate Research Network (CRN)	USA+	144		http://www.ncdc.noaa.gov/oa/climate/uscrn/
National Ecological Observatory Network (NEON)	USA	20		http://neoninc.org/
SNOTEL	Western USA	750		http://www.wcc.nrcs.usda.gov/snow/
Oklahoma Mesonet	Oklahoma	127		http://www.mesonet.org/
ARM-SGP	Oklahoma/Kansas	31		http://www.arm.gov/sites/sgp
Illinois Climate Network (ICN)	Illinois, USA	19		http://www.sws.uiuc.edu/warm/datatype.asp
High Plains Regional Climate Center (HPRCC)	Nebraska, USA	53		http://www.hprcc.unl.edu/awdn/soilm/index.php?action=More+About+This+Project
Mongolia Validation (GCOM-W)	Mongolia	14		http://monsoon.t.u-tokyo.ac.jp/camp-i/
Little Washita (ARS)	Oklahoma, USA	20		http://www.ars.usda.gov/main/site_main.htm?modecode=62-18-05-20
Fort Cobb (ARS)	Oklahoma, USA	15		http://www.ars.usda.gov/main/site_main.htm?modecode=62-18-05-20
Little River (ARS)	Georgia, USA	29		http://www.ars.usda.gov/main/site_main.htm?modecode=66-02-05-00
Walnut Gulch (ARS)	Arizona, USA	21		http://www.ars.usda.gov/main/site_main.htm?modecode=53-42-45-00
Reynolds Creek (ARS)	Idaho, USA	15		http://www.ars.usda.gov/main/site_main.htm?modecode=53-62-00-00
Walnut Creek (ARS)	Iowa, USA	9		http://www.ars.usda.gov/Main/site_main.htm?modecode=36-25-15-00
Sonora	Mexico	14		http://vivoni.asu.edu/sonora/www/pages/hydromet.html
Saskatchewan	Canada	16		aberg@uoguelph.ca
Kenaston	Canada	24		brenda.toth@ec.gc.ca
Ontario	Canada	26		aberg@uoguelph.ca
REMEDHUS-Salamanca	Spain	23	X	http://campus.usal.es/~hidrus/
Valencia Anchor Site	Spain	11		http://www.uv.es/elopez/?21
SMOSMANIA	France	12	X	http://www.hymex.org/
Upper Danube Basin	Germany	10		alexander.loew@zmaw.de
Yanco	Australia	13	X	http://www.oznet.org.au/
Kyeamba	Australia	14	X	http://www.oznet.org.au/
Goulburn	Australia	20	X	http://www.oznet.org.au/
Adelong Creek	Australia	5	X	http://www.oznet.org.au/
Mumbridgee	Australia	7	X	http://www.oznet.org.au/
West Africa	Africa	TBD		TBD
South African Weather Service	South Africa	TBD		TBD
La Plata Basin	Argentina	TBD		TBD

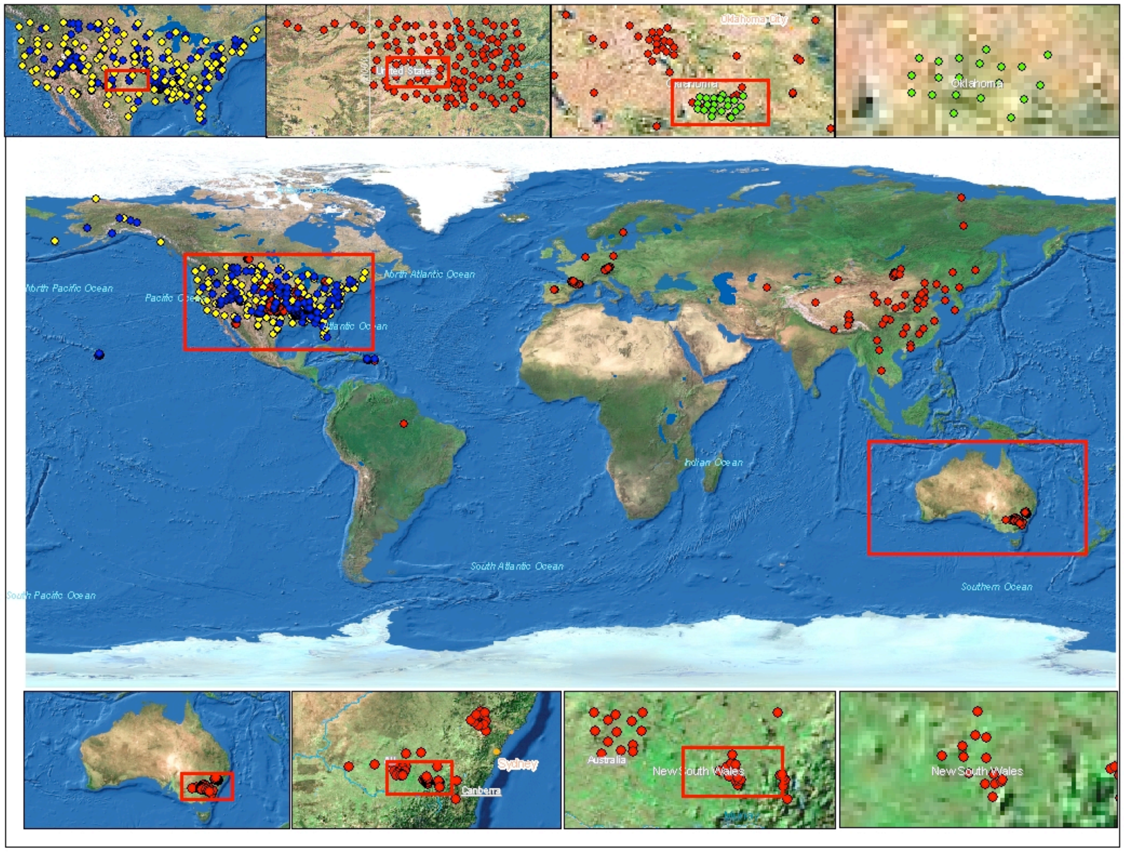


Figure 3-1. In Situ Soil Moisture Resources (v. May 2008). The top panel shows (from left to right) the SCAN and CRN, Oklahoma Mesonet, and Little Washita Networks. The bottom panel shows Australia and a sequence of enlargements to the Kyeamba area.

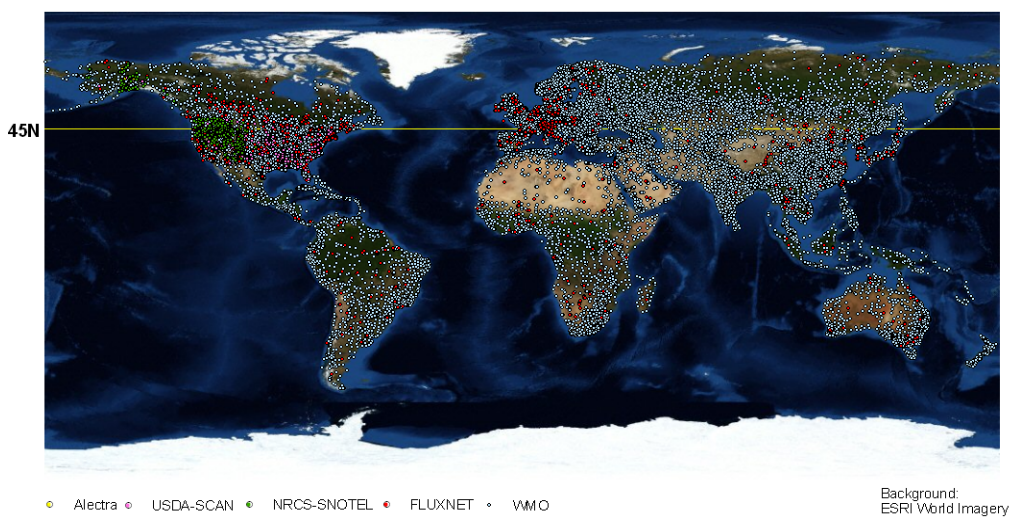


Figure 3-2. World Meteorological Organization's (WMO) global meteorological observation station network (the white dots) with ALECTRA, USDA-SCAN, NRCS-SNOTEL, FLUXNET networks (see Table 3-1). Note that the WMO sites cannot be used directly for comparison with satellite products since they do not measure soil moisture or freeze/thaw state.

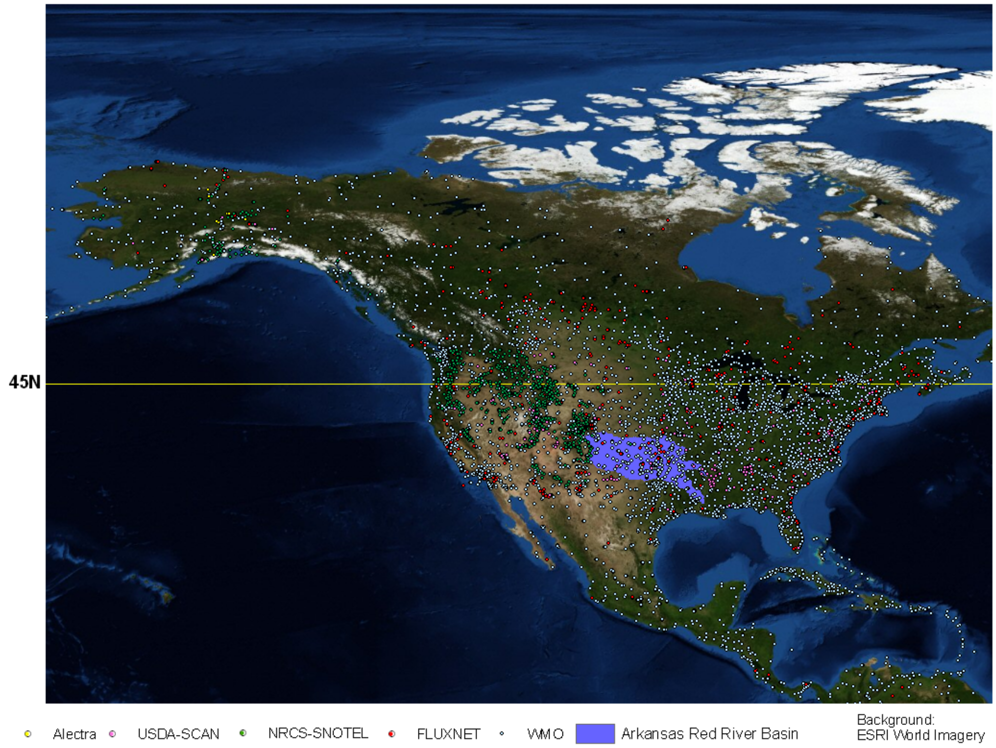


Figure 3-3. WMO's meteorological observation stations in North America (the white dots) with ALECTRA, USDA-SCAN, NRCS-SNOTEL, FLUXNET networks (see Table 3-1). The Arkansas Red River Basin is marked with blue color. The basin contains among others over hundred observation stations by Oklahoma Mesonet. Note that the WMO sites cannot be used directly for comparison with satellite products since they do not measure soil moisture or freeze/thaw state.

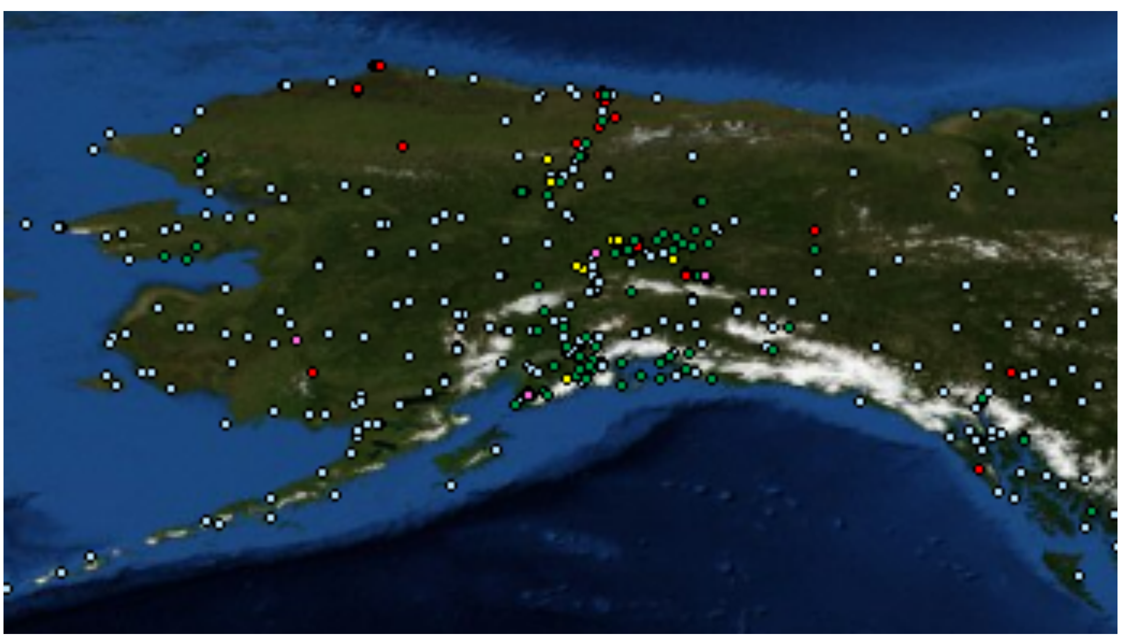


Figure 3-4. ALECTRA network stations (the yellow dots) with FLUXNET (red dots), SNOTEL (green dots), SCAN (pink dots) and WMO (white dots) network sites in Alaska.

3.3.1.1 Comments on In Situ Soil Moisture Measurement

In situ measurement and scaling of soil moisture presents many challenges. As a result, there are a wide range of measurement techniques and protocols that have been adopted in practice. The value of an observing program to SMAP validation will depend upon (a) the quality of the measurements, (b) how the measurement relates to the validation criteria (in particular the depths and scales), and (c) the availability of the data in a timely manner. The following discussion focuses on the first two issues.

Although the providers of in situ data are likely to have conducted an assessment of the quality of their measurements, if adequate calibration has not been conducted the SMAP project will cooperate in implementing an assessment before using the data for validation.

In situ resources that will be the most relevant for SMAP soil moisture calibration and validation would provide an estimate of the volumetric soil moisture over the surface 5 cm and the 100 cm depth of soil. In general, this will involve two steps: 1) establishing that the sensor provides the equivalent of the volumetric soil moisture that would be obtained using a reference standard, and 2) if the sensor does not actually measure the defined layer, providing verification that the sensor values are well correlated to the mission product depths (0-5 and 0-100 cm). It should be noted that the 0-5 cm measurement is the highest priority and that this measurement is logistically easier to obtain and verify than the 0-100 cm depth measurement.

The recommended reference standard for characterizing volumetric soil moisture is the thermo-gravimetric (usually shortened to gravimetric) measurement method (Chapter 3.1.2.1 in [10]). This technique is time consuming to implement operationally; therefore, it is usually only used for calibration of sensors and in field campaigns. The soil moisture in a known volume (cm^3) is characterized by weighing, then drying, and weighing again to obtain the mass of water (gm). With a specific density of 1 cm^3/gm for water, the result is the volumetric soil moisture (cm^3/ cm^3).

Most sensor manufacturers provide a calibration function for converting the sensor signal to soil moisture (some do not actually provide volumetric soil moisture but an alternative variable such as moisture-tension). These calibrations are often based on limited laboratory studies and are often soil type specific; thus requiring site characterization for a more accurate estimate. Some operational networks have conducted supplemental laboratory analyses to improve their products. An advantage of laboratory calibration is that a full range of soil moisture can be examined.

An alternative, or in some cases a complement, to laboratory calibration is site-specific calibration. The advantage of a site-specific calibration is that it incorporates soil type correction and peculiarities associated with the installation. As described later, it can also be used to correct for measurement depth differences. Disadvantages include repetitive site visits to capture a range of conditions and potential impacts from destructive sampling. Also, his approach is much easier to implement for surface layer measurements than the full profile.

The most straightforward way to provide both items above is to sample the 0-5 cm soil layer using a volume extraction method, such as a ring coring tool.

The other aspect that must be considered regarding the use of in situ observations for SMAP validation is how the measurement relates to the depths defined in validation criteria, Each type of sensor measures a different volume and different networks utilize different installation protocols that can result in incompatibility. SMAP is supporting studies, specifically the In Situ Sensor

Testbed described in a later section, to provide a basis for normalizing these different methods and protocols, especially if it becomes the SMAP Projects responsibility to do so.

Performing a site-specific calibration against a standard of gravimetric measurement of the 0-5 cm soil layer (and 0-100 cm if possible) is the recommended protocol for calibration and normalizing an in situ network for integration into the SMAP validation data base.

3.3.1.2 Scaling Methodologies and Heterogeneity

In situ observations are usually made point-wise and the problem in using point measurements for the validation of a measurement over a sizeable footprint is the representativeness of those point measurements with respect to the footprint measurement. In order to use the point measurements for the validation of the footprint measurement a scaling methodology must be used.

One approach that has been successfully used is temporal, or rank, stability, since the method is based on investigating which measurement point of an area gives the most stable response for the variable over time and then that measurement is used to represent the area [11], [12]. This method may be enhanced with ancillary data to improve the estimation of the temporally stable point.

Statistical tools can be used to characterize the sampling points to establish reliability to the scaling process. One example of this approach, called statistical replication, is presented in [13]. Finally, a geophysical model can be used to characterize the area and to relate the point measurements to the regions whose relevance and representativeness can be evaluated through the model [14]. Additional approaches are being developed, as described in a later section that may lead to a solution.

In testing and validating these methods tower and airborne observations are crucial to characterize the field sites and regions where the scaling is supposedly going to take place. Especially, when the land cover introduces additional heterogeneity over the area, having a remotely sensed reference for the surface parameters is even more critical in the process of translating the point measurements to the satellite footprint scale.

3.3.2 Tower and Aircraft-based Radiometers and Radars

Tower-based and airborne microwave sensors play important roles in Earth remote sensing. Tower-based systems can provide continuous observations of relatively small areas. Smaller footprints are very useful in controlled condition experiments, which are vital in advancing our understanding of microwave emission and scattering. These observations provide the basis of models and algorithms. Tower sensors are also the most efficient means of obtaining temporal information. Phenomena ranging from minutes (infiltration) to days (evapotranspiration) or weeks (crop growth) can be observed.

Airborne sensor systems complement tower observations by providing an intermediate spatial scale that links to the satellite footprint. Understanding the scaling of the basic sensor measurement (i.e. brightness temperature and radar backscatter) as well as the geophysical variable that is being retrieved (i.e. soil moisture and freeze/thaw status) is critical to satellite-based remote sensing. These platforms facilitate the observation of a wide range of target features and experimental sample replication, which are logistically difficult with towers. Airborne systems are valuable in the demonstration and verification of algorithms and applications in that they can be used to map a spatial domain.

An important aspect that needs to be considered is the calibration of the instruments and their compatibility with the satellite configuration. At the pre-launch stage of the project, highly accurate and representative data sets are necessary for algorithm refinement. These topics are the subject of discussion by the community, with a goal of some level of standardization.

To support SMAP Cal/Val a survey of existing and planned L-band tower and airborne instruments, and synergistic mission data, was conducted by the SMAP Science Definition Team (SDT) Cal/Val Working Group. The results are provided in Table 3-2. Information was provided by the groups operating each sensor system. Some systems may not be included due to lack of response to the survey or lack of knowledge by the SDT of their existence. These can be identified and added in a future update. For a full list of participants in the survey, see [15].

It should be noted that the number of stand-alone passive tower systems is much greater than the available combined systems. This is largely the result of activities related to SMOS, which is a passive system. Also, there is a relatively large data base of experimental passive observations. There are fewer relevant radar data sets and very few combined active/passive. The most valuable system to SMAP would provide the combined observations.

Table 3-2. Existing L-band Tower and Aircraft-based Sensors

Tower Systems	**Airborne Systems**
Combined Passive and Active	**Combined Passive and Active**
ComRAD	*PALS*
VLR2	*PLMR/PLIS*
Passive	*CAROLS/STORM*
TMRS-3	*RadSTAR2*
UFLMR	*PSR/L: LAIS*
ISMR	**Passive**
SWAMP	*2D-STAR*
TSMR	*AMIRAS*
JULBARA	*HUT-2D*
RADOMEX	*EMIRAD-2*
LAURA	*IROE*
ELBARA	*Radius/Ranet*
EMIRAD-1	*MAPIR*
PLR	*LDCR*
LNIR	*ECMR*
MERITXEL	**Active**
PAU	*UAVSAR*
Active	*E-SAR*
MOSS	*Pi-SAR*
UMS	
HPS	

Recommendations to the SMAP Project were made following earlier SDT and Cal/Val Working Group meetings concerning actions to insure instrumentation that would provide the data needed to support Cal/Val. These included improving the quality and operations of the tower-based ComRAD and adding scanning capability for PALS. Both of these have been initiated.

3.3.3 Utilization of Homogenous Targets

Homogeneous areas over the Earth's surface are especially interesting for the calibration and validation of instruments and algorithms, primarily Level 1 products. These areas, in principle, have good representativeness for point measurements and they are easy to model, primary resulting from the lack of heterogeneity within the footprint. Naturally, the areas have to be homogeneous over the entire footprint of the instrument: in the case of SMAP this means tens of kilometers for the diameter of the area. Additionally, if the homogeneous area is larger then it is more likely that the antenna main beam and the side lobes will measure the same target, which adds to the accuracy. Furthermore, it is very desirable that the area is temporally stable (particularly at the overpass time). The observed stability of the target depends on the stability of the source medium over the penetration depth, which is determined by the measurement frequency of the instrument.

Samples of homogeneous areas are ocean surfaces, thick ice sheets and glaciers, deserts and large rain forests. Considering the L-band observations of SMAP, the large penetration depth may make the ice sheets more attractive [16]-[19] and rain forests less attractive [20],[21] regions in terms of stability when compared to the use with higher frequencies. The targets need to be characterized in a way depending on how they will be used in the calibration and validation. For example, if the target is a vicarious stability reference it is adequate just to know how stable the target is over time, but if it is used as an absolute reference then exact a priori knowledge of the emission and scattering properties need to be known.

An additional homogeneous and well characterized target is the Cosmic Microwave Background (CMB) of space, which needs to be complemented with a map of celestial objects to account for their emission at L-band.

3.3.4 Synergistic Satellite Observations

Observations by other satellite instruments both before and after launch can be utilized for calibration and validation of SMAP. For pre-launch calibration and validation the primary role of spaceborne observations will be the testing of algorithms, using Level 1 products to produce SMAP Level 2 and 3,. Level 2 products from these missions can be used to evaluate the SMAP algorithm performance. For post-launch calibration and validation the alternative mission observations will provide products which can be compared with those from SMAP.

The following lists some of the most relevant satellite products that could be used before and/or after the launch for SMAP calibration and validation (responsible agency and launch year in parenthesis):

- SMOS (ESA, 2009): Global L-band horizontal and vertical polarization brightness temperature and surface soil moisture; pre-launch and post-launch
- ALOS PALSAR (JAXA, 2006): Multiple resolution backscatter product based on L-band SAR; pre-launch
- MetOp ASCAT (ESA, 2006): Soil moisture index based on C-band backscatter; pre-launch and post-launch
- Aquarius (NASA/CONAE, 2011): Simultaneous L-band TB and backscatter; experimental soil moisture product; pre-launch and post-launch
- GCOM-W AMSR-2 (JAXA, 2012): Soil Moisture product based on C-band brightness temperature; pre-launch and post-launch

- SAOCOM (CONAE, 2012): Backscatter and Soil Moisture product based on L-band SAR; pre-launch and post-launch
- ALOS-2 PALSAR (JAXA, 2012): Multiple resolution backscatter product based on L-band SAR; possibly pre-launch and post-launch

These satellites programs measure either brightness temperature or backscatter at L-band (Aquarius provides both) and/or produce a soil moisture product from their observations. The options and the value of these other satellites depend largely on the overlap of the mission with SMAP. However, for example, in the case of SMOS the measurements of brightness temperature will be extremely valuable, even if the data are limited to the pre-launch period, because they represent the first L-band brightness temperature measurements from space. Cross-calibration exercises between different satellite instruments have been successfully carried out improving the quality of the time series created by the instruments in question (e.g. [22]-[24]). For inter-comparisons between the satellites, the product accuracy requirements of the other missions are of significance. The most relevant inter-comparison mission is SMOS (since it is L-band), which has soil moisture accuracy requirements equivalent to SMAP.

These comparisons will be limited by the quality of the alternative product, differences in overpass time and days, and accounting for system differences affecting the soil moisture product. For example, in the case of GCOM-W which is planned for a 01:30 am / 01:30 pm overpass time, confusion factors would include data at a different time of day (from the SMOS/Aquarius/SMAP overpass time of 06:00 am) and contributing depth issues [25].

3.3.5 Model-based Validation Approaches

As discussed in previous sections, many in situ validation resources have scaling and coverage issues. Hydrological land surface models can be used to complement direct in situ based validation.

In the simplest case, hydrologic modeling can be used to generate soil moisture products at larger (basin-wide and continental) scales using assimilated data that is independent of the remote sensing data. Several different models have been developed which can be applied. The resulting soil moisture fields can then be compared with the remotely sensed soil moisture product at validation sites over diurnal and seasonal cycles. These model-derived soil moisture fields can also be used to extend the comparisons to larger space and time domains than available from in situ observations.

The above approach can be enhanced with in situ data. For example, the so-called triple collocation technique provides a means to systematically estimate RMSE values and biases between three independent data sources [26]. This approach could also decrease the effect of scaling errors of the in situ measurement on the validation process.

Another possibility is to use data assimilation process and proxy parameters, such as model precipitation error and rain gauge measurements, to estimate the surface soil moisture. The remotely sensed soil moisture product would then be validated in relative terms against this output [27], [28]. Additionally, the models can be run against brightness temperature products by applying a brightness temperature forward model on the land surface model.

It should also be noted that several Numerical Weather Prediction (NWP) models produce routine soil moisture fields at a scale comparable to the SMAP radiometer product. These include ECMWF, GMAO, and NCEP. Although there are many caveats that need to be considered in using these data, they are readily available and at least one will be ingested, along with surface temperature, into the

SMAP data stream. At this stage, we do not know how to effectively use NWP products in validation; however, they can be a valuable supplemental resource.

3.3.6 Field Experiments

Airborne field experiments serve a valuable role during pre-launch by providing diverse but controlled condition data for developing algorithms, establishing algorithm parameterization, and defining validation site scaling properties. Post-launch airborne field experiments can be used, for example, to Level 1 product validation, resolve fine resolution features over validation sites for more accurate comparison with the satellite products, and increase the temporal fidelity of remote sensing measurements over the validation sites.

Field experiments that address microwave soil moisture algorithm issues and/or applications are listed in Table 3-3. The experiments also complement pre-launch (and post-launch) studies with SMOS, Aquarius and ALOS PALSAR data. The Table shows also the launches of these relevant satellites. Experiments indicated in red address SMAP algorithm issues specifically.

Table 3-3. Field Experiments and Satellite Launches

Year \ Quarter	**1**	**2**	**3**	**4**
2008		Europe	SMAPVEX08	
2009				***SMOS***
2010	AACES (I) Europe	CanEx-SM10 SMAPEx 1 Europe	AACES (II)	SMAPEx 2
2011	SMAPEx 3	***Aquarius***	SMAPEx 4	CanEx-FT:Fall
2012	***GCOM-W*** CanEx-FT:Spring	***ALOS-2*** SMAPVEX12	***SAOCOM***	
2013				
2014				***SMAP***
2015		SMAPVEX15		

4 CALIBRATION AND VALIDATION REQUIREMENTS OF SMAP PRODUCTS

The SMAP data products are listed earlier in Section 2 (Table 2-4). The requirements for these products are listed in Appendix B. Assessing if these requirements are met is the primary objective of the Cal/Val Plan. The requirements for the algorithms, i.e. ATBDs, flow down from these product requirements (see Section 2.3.1). In the ATBDs, each product algorithm team identifies what calibration and validation activities are needed to meet the product requirements. These activities then become another set of requirements for the Cal/Val Plan. This Chapter focuses on detailing the requirement defined by the ATBDs, and the subsequent Chapters describe how the Cal/Val Program addresses these requirements together with the other mission requirements. Note that in order to maintain the consistency in this process all central terms and definitions used in requirement documents, ATBDs, and this document follow the definitions given in [7].

4.1 Level 1 - Sensor Products

Level 1 SMAP science products are the calibrated sensor outputs (brightness temperature and radar backscatter). The accuracy of these products depends on the pre-launch calibration model and the calibration algorithm and coefficients applied in the post-launch processing.

Table 4-1 shows the Level 1 products, their requirements for spatial resolution and accuracy, and associated pre-launch and post-launch cal/val requirements. Products L1B_TB [29] and L1C_TB [30] are time-ordered and swath- and Earth-gridded (collocated with radar) brightness temperatures, respectively. Products L1B_S0_LoRes [31] and L1C_S0_HiRes [32] are the low resolution (real aperture) and high resolution (synthetic aperture) radar cross-sections, respectively.

Separate calibration documents will be produced for the sensors. The pre-launch calibration of the radiometer is described in [33].

Table 4-1. Level 1 products and associated cal/val requirements. The columns are divided for product type; spatial resolution of the instrument output for L1B_TB, L1B_S0, L1C_S0 and grid resolution for L1C_TB; accuracy for horizontal and vertical polarization, and for 3rd Stokes parameter of radiometer and HV-combination of radar; and pre-launch and post-launch cal/val requirements.

Level 1	Reso	Accuracy		Cal/Val Requirements	
Products	[km]	H/V	3/ HV	Pre-Launch	Post-Launch
L1B_TB	40	1.3 K	-	• High-level output coaxial noise source with 0.3 K accuracy (to be modified from existing source called RATS) • Polarimetric coaxial noise source (existing source called CNCS [34]) • L-band warm blackbody (for feed horn) with return loss > 35 and thermal stability of 0.2°C (existing) • L-band LN2-cooled blackbody with 1 K accuracy (existing) • Controlled thermal environment • Antenna pattern and reflector emission verified by antenna team [1]	• Pre-launch calibration parameters • Sky TB map for CSC (accuracy TBD K) • Ocean and land target RTM with overall 0.4 K uncertainty • Geolocation: Antenna pointing information; ocean RTM; coastlines • Faraday rotation: IRI and IGRF databases; Aquarius and SMOS values; Rotation angles from astronomers, geostationary satellites and GPS satellites • Atmospheric correction: global temperature and humidity profiles • Antenna pattern correction: Nominal antenna pattern; Antenna pointing information; SMAP TB Forward Simulator [2,3] • Aquarius radiometer brightness temperatures • SMOS radiometer brightness temperatures • Aircraft-based observations during field campaigns
L1C_TB	36	1.3 K	-	• C-band AMSR-E data over Florida region; • Prototype SMAP-like data set from the Testbed over Florida region	• SMAP L1B and L1C data over TBD locations, where the grids coincide with time ordered locations;
L1B_S0	30	1 dB	1.5 dB	• TBD	• Sky TB map for CSC (accuracy TBD); • Pre-launch calibration parameters; • Established uniform, isotropic, stable Earth targets; • Data from contemporaneous radars (Aquarius, PALSAR, UAVSAR, SAOCOM, etc.); • Aircraft-based observations during field campaigns • Receive only data acquisition (for RFI)
L1C_S0	3	1 dB	1.5 dB	• TBD	• L1B_S0; • Checks for scalloping…

(1) The radiometer development, implementation and calibration is the responsibility of GSFC. The antenna development, implementation, testing and characterization is the responsibility of JPL.

(2) SMAP Brightness Temperature (TB) Forward Simulator: based on ocean and land surface radiative transfer model (RTM). The simulator includes the following sources and effects included:

- Solar direct, reflected
- Lunar direct, reflected

- Galactic direct, reflected
- Land, atmosphere, ocean
- Faraday rotation
- Antenna sidelobes

(3) Assumptions in current error budget

- Earth sidelobe scene known to 6 K
- Cross-pol TB known to 2 K
- Space scene known to 1 K
- Solar flux known to 20 s.f.u.

4.2 Level 2 and 3 - Geophysical Products

Level 2 products contain derived geophysical parameters (soil moisture, freeze/thaw) whose accuracy depends on the accuracy of the input Level 1 sensor data and the Level 2 geophysical retrieval algorithms.

Table 4-2 shows the Level 2/3 products, their requirements for spatial resolution, accuracy, and revisit time, and the associated cal/val requirements. Products L2_SM_P [35], L2_SM_A [36] and L2_SM_AP [37] are soil moisture products (top 5 cm of soil), based on radiometer-only, radar-only, and combined radar-radiometer data, respectively. Product L3_FT_A [38] is the freeze/thaw state product, based on radar data only.

Table 4-2. Level 2/3 products and associated cal/val requirements. The columns are divided by product type; grid resolution; accuracy requirement of the product; revisit time; pre-launch and post-launch cal/val requirements.

Level 2/3	Reso	Acc.	Rep	Cal/Val Requirements	
Products	[km]		[d]	Pre-Launch	Post-Launch
L2_SM_P	36	0.04 m^3/m^3	3	• Ancillary data sets needed by baseline and option algorithms; • Global Testbed (GloSim) retrieval simulations using synthetic observation conditions; • Field experiment data (SGP99, SMEX02, CLASIC, SMAPVEX08, CanEx-SM10, SMAPVEX12) for surface SM[1]; • SMOS brightness temperature and soil moisture products, ancillary data and validation products	• Algorithm parameterization established; • In situ core sites[2]; • Field experiments[1]; • In situ sparse networks; • SMOS, GCOM-W and ASCAT soil moisture products; • Independent hydrologic model outputs
L2_SM_A	3	0.04 m^3/m^3	3	• Ancillary data sets needed by baseline and option algorithms; • Global Testbed (GloSim) retrieval simulations using synthetic observation conditions; • Field experiment data (SGP99, SMEX02, CanEx-SM10, tower-based campaigns) for surface SM[1,1b]; • Satellite (PALSAR) data	• Algorithm parameterization established; • In situ core sites[2]; • Field experiments[1]; • In situ sparse networks; • ALOS-2 and SAOCOM soil moisture products; • Independent hydrologic model outputs;
L2_SM_A/P	9	0.04 m^3/m^3	3	• Ancillary data sets needed by baseline and option algorithms; • Global Testbed (GloSim) retrieval simulations using synthetic observation conditions; • SGP99, SMEX02, CLASIC, SMAPVEX08 data sets; • Multi-scale airborne field experiment[1] data capturing changes in the vegetation conditions	• Algorithm parameterization established; • In situ core sites[2]; • Field experiments[1]; • In situ sparse networks; • Independent hydrologic model outputs;
L3_FT_A	3	80 %	2	• Ancillary data sets needed by baseline and option algorithms; • Global Testbed (GloSim) retrieval simulations using synthetic observation conditions • Testbed simulations with in situ sparse networks (NRCS Snotel, SCAN, FLUXNET, ALECTRA, WMO) frozen/non-frozen status and SMOS and PALSAR; • SMOS, PALSAR, PALS time series data over test regions; • Field experiments over complex terrain and land cover [3];	• Algorithm parameterization established; • In situ sparse networks (NRCS Snotel, SCAN, FLUXNET, ALECTRA, WMO) frozen/non-frozen status; • Field experiments (e.g. PALS) with in situ sparse network sites (e.g. FLUXNET)

(1) Surface soil moisture (SM) experiments have the following minimum requirements (subsite is a part of the experiment domain, such as a field):

- The soil moisture in the top 5 cm can be determined with dielectric probes with point location specific calibration through bulk density and thermo-gravimetric core sampling, which yields sample uncertainty no more than 0.04 cm^3/cm^3.
- The spatial sampling of surface SM is done following the methodology established for that specific location
- The soil texture is to be determined for each sampling point specifically through bulk density core samples.
- The land cover is classified according to the classes used for the SMAP products.
- The vegetation is classified according to the classes used for the SMAP products.
- The vegetation water content measurements are calibrated through destructive thermo-gravimetric sampling.
- Soil temperature is determined at each sampling point. Site specific meteorological state is determined for air temperature and precipitation.

(1b) Some geophysical input parameters have greater impact on the radar soil moisture error (as opposed to the radiometer soil moisture) than others (such as roughness, albedo, and VWC, according to a retrieval experiment with empirical radar scattering model) therefore, attention needs to be paid to accounting for these parameters over the experiment sites. The procedures for doing this need to be established in the pre-launch phase. Furthermore, the fact that radar is more sensitive to the incidence and azimuth angle of the measurement than radiometers needs to be considered in the experiments.

(2) In situ dense sampling sites (meaning an intense measurement site with established scaling from point measurements to satellite footprint) used in the post-launch soil moisture validation need to satisfy the following requirements:

- The soil moisture measured must provide an estimate of the state of the top 5 cm with well defined uncertainty brackets
- The spatial sampling of the site must be such that a defined resolution scaling scheme can be applied.

(3) In situ frozen/non-frozen status will be determined as a composite ensemble of vegetation, soil and air temperature measurements where available, and will be compared to coincident footprint scale L3 freeze/thaw measurements for areas of the globe where seasonally frozen temperatures are a major constraint to hydrological and ecosystem processes. The fulfillment of the requirements will be assessed by comparing SMAP freeze-thaw classification results and in situ frozen or non-frozen status. The in situ resource should provide a strategy for spatial upscaling of in situ measurements commensurate with the 3 km spatial scale of the satellite retrieval. Attention should be given to landscape heterogeneity within the scope of the validation site or sites in the upscaling strategy.

Measurements supporting freeze-thaw cal/val activities should meet the following minimum requirements:

- Measurement of surface (screen height) air temperature
- Measurement of surface (up to 10 cm depth) and profile (up to 1 m depth) soil temperatures
- Measurement of vegetation temperature (when significant vegetation present)
- In situ temperature measurements should be sufficient to characterize the variability in local microclimate heterogeneity within a spatial scale compatible with the SMAP freeze-thaw product.
- To provide uniformity across sites, the local land cover of the site should be consistent with a global (IGBP-type) land cover classification
- Each land cover class within the validation site should be captured within the suite of

temperature measurements such that the local vegetation and land cover heterogeneity is represented.

- Measurements should have sufficient temporal fidelity to capture seasonal and diurnal temperature and freeze-thaw patterns.

Desired methods for measuring air, soil, and vegetation temperatures include thermocouple type measures of physical temperatures and thermal IR type measurements of surface “skin” temperatures with consistent and well documented accuracy and error sources over a large (e.g. -30°C to 40°C) temperature range.

4.3 Level 4 - Geophysical Products

Level 4 products contain geophysical parameters whose accuracies depend on the accuracies of the input Level 1 and Level 2-3 data products, other input data, and the model and assimilation technique.

Table 4-3 shows the two Level 4 products, their requirements for spatial resolution, accuracy, revisit time, and the associated cal/val requirements. L4_SM [39] is a surface and root-zone soil moisture product, and L4_C [40] is a net ecosystem exchange (NEE) product.

Table 4-3. Level 4 products and associated cal/val requirements. The columns are divided by product type; grid resolution; accuracy requirement of the product; revisit time; pre-launch and post-launch cal/val requirements.

Level 4	Reso	Acc.	Rep	Cal/Val Requirements	
Products	[km]		[d]	Pre-Launch	Post-Launch
L4_SM	9	0.04 m^3/m^3	TBD	• Testbed simulations; • Satellite observations (SMOS, Aquarius, PALSAR); • In situ networks; • Internal data assimilation diagnostics	• Surface SM: see Level 3; • Root-zone SM: In situ networks (SCAN, CEOP, Oklahoma Mesonet, USCRN, GPS, COSMOS); • Precipitations observations; • Internal data assimilation diagnostics
L4_C	9	30 $gC/m^2/yr$	TBD	• Satellite data (e.g. MOD17 product); • GMAO LIS; • In situ CO2 eddy flux (e.g. FLUXNET) • Internal data assimilation diagnostics	• GMAO L4 SM; • In situ CO2 eddy flux (e.g. FLUXNET) [1]

(1) The accuracy of the L4_C outputs, including NEE and component carbon fluxes will be established in relation to in situ tower eddy flux CO_2 measurements and associated carbon budgets within regionally dominant vegetation classes following established protocols. The fulfillment of the NEE requirement will be assessed by comparing SMAP L4_C NEE output with in situ measurement-based CO_2 flux estimates.

In order for a flux tower to be useful for NEE validation, it has to provide at minimum the following measurements:

- Continuous daily (cumulative 24-hr) estimates of gross primary production (GPP), ecosystem respiration (R_{eco}), and NEE with well defined and documented accuracy, including both systematic and random errors;

- Relatively homogeneous land cover and vegetation conditions within an approximate 10 km x 10 km footprint commensurate with the resolution of the SMAP L4_C product;
- To provide uniformity across sites, the local land cover of the site should be compatible with a global (IGBP-type) land cover classification;
- The local site should have a minimum level of supporting meteorological measurements including air temperature and humidity, surface (≤10 cm depth) soil moisture and soil temperature, precipitation, and snow depth (if present); these measurements should be continuously monitored and sufficient to capture local microclimate heterogeneity within the tower footprint.
- The local site should have a minimum level of supporting biophysical inventory measurements including surface (≤10 cm depth) soil organic carbon stocks, vegetation stand age class, land use, and disturbance history.

4.4 Prioritization of Geophysical Algorithm Risk-Reduction Issues

Table 4-4 summarizes algorithm issues that influence accuracies of the Level 2/3 and geophysical retrieval algorithms. The entries are based on the Level 2/3 ATBDs for the soil moisture and freeze/thaw algorithms. The tables provide a focus for prioritization of pre-launch Cal/Val activities in addressing areas of risk-reduction in the algorithm development.

The table rows list algorithm issues, while the columns list the four Level 2/3 products. Filled dots in the table mean that the issue needs more input data (such as field experiment data, improved data source or processing, etc.) to bring the product retrieval algorithm to the required level. Empty dots mean that new input data would be useful for improving the product but is not strictly necessary to have confidence that the product requirements can be met. Vacant cell means that there is no issue with respect to the product in question.

Based on Table 4-4 it can be concluded that most important issues to be addressed in the algorithm development are performance of the time series method, heterogeneity within the pixel, resolution scaling of the measurement, effects of the topography, and effects of different land cover types. Additionally, the mitigation of the RFI in the measurements is a major concern. Regarding the quality of the ancillary data soil moisture and VWC require the most attention. Also the masks of dense vegetation, mountain area and urban areas need further development.

Table 4-4. Level 2 Algorithm Issues and Prioritization

	Level 2/3 Product			
Issues	**SM P**	**SM A**	**SM A/P**	**FT**
Algorithm questions				
Algorithm selection	○	●	●	○
Time series performance		●	●	●
Heterogeneity	●	○	●	●
Azimuthal dependency		●	○	○
Resolution scaling	●	●	●	○
Topography effects	●	●	●	●
Separability soil and vegetation				●
Vegetation types	●	●	●	○
RFI mitigation	●	●	●	○
Ancillary data				
Soil temperature	●	○	●	
Vegetation temperature	○	○	○	
Soil texture	○	○	○	○
Roughness	○	●	○	○
VWC	●	●	●	○
Dense vegetation mask	●	●	●	●
Mountain mask	●	●	●	●
Land cover mask	●	●	●	●
Urban area mask	●	●	●	●
Water body mask	○	○	○	○
Freeze/snow mask	○	○	○	
● - New input required				
○ - New input useful but not required				
Vacant - Not an issue				

5 PRE-LAUNCH ACTIVITIES

5.1 Overview

During the pre-launch period there are a variety of activities that fall under calibration and validation. These mainly involve calibration, algorithm development and evaluation, and establishing the infrastructure and methodologies for post-launch validation.

Requirements for Cal/Val related to specific SMAP data products have been identified by the respective science algorithm teams in their Algorithm Theoretical Basis Documents (ATBDs) and these will likely be added to over time. The ATBDs are developed in Phases A and B of the mission so that the production processing algorithms can be coded and tested in Phase C/D. Pre-launch activities will include development of the calibration procedures and algorithms for the SMAP radar and radiometer (Level 1 products), development of surface soil moisture and freeze-thaw state algorithms (Level 2-3 products), and development of a surface to root-zone soil moisture product and carbon exchange product (Level 4 products).

Pre-launch instrument calibration will include modeling, analysis, simulations, and laboratory and test-facility measurements. Algorithm development for all products will include testbed simulations, laboratory and test-facility data, field campaigns, exploitation of existing in situ and satellite data, and utilization of instrument and geophysical models. Controlled-condition tower and aircraft experiments using SMAP measurement prototypes, and utilization of e.g. SMOS, Aquarius and PALSAR satellite data and model products, will be included. This Section details these activities.

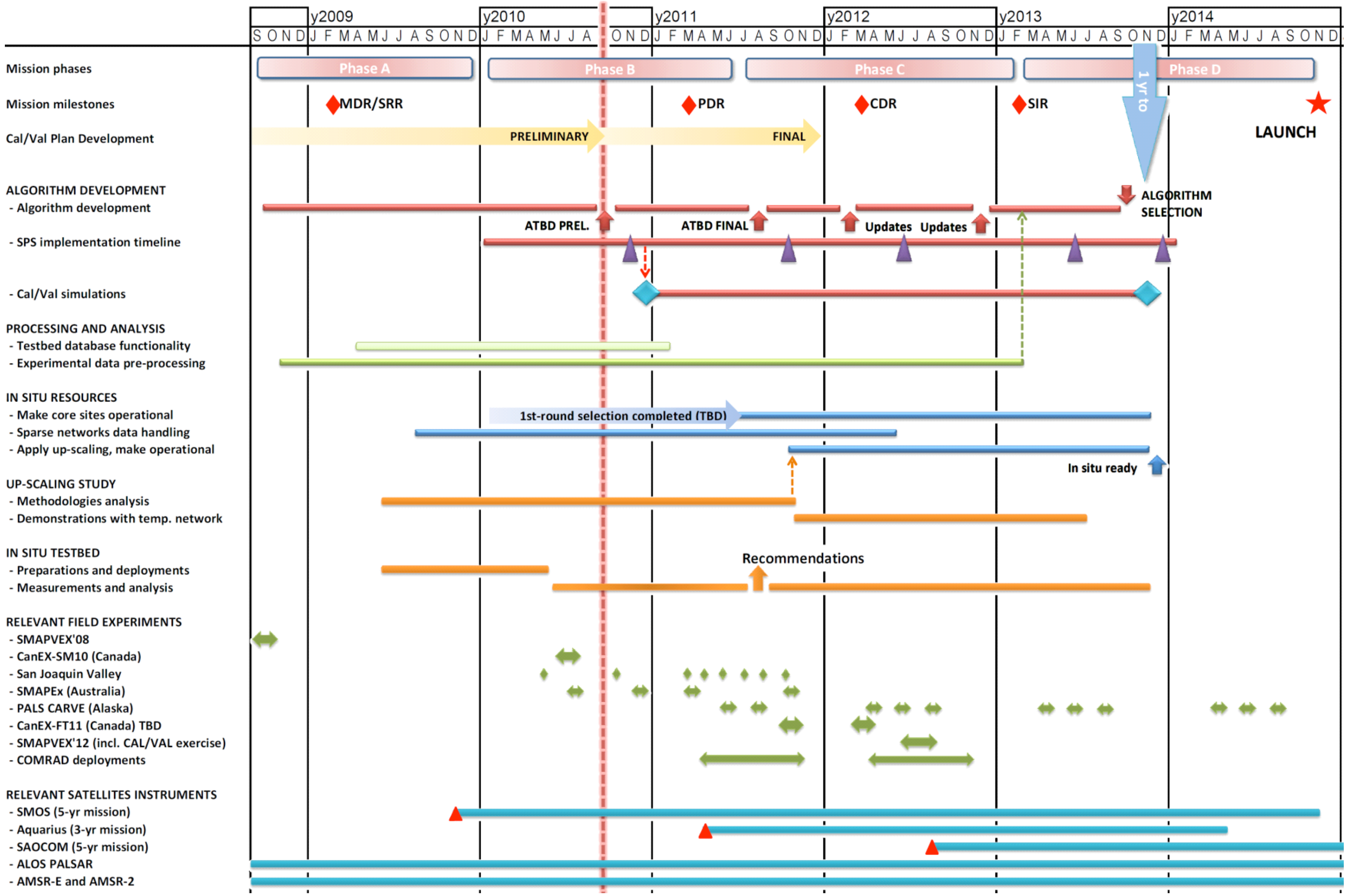
5.2 Pre-Launch Cal/Val Timeline

Table 5-1 shows a draft timeline for pre-launch Cal/Val activities. The timeline shows key Cal/Val activities and related project schedule items. The timeline includes the project phases and algorithm and software delivery schedules. The table also indicates timing of field campaigns. The final versions of algorithm ATBDs are due well before CDR, however, it is expected that the algorithms and their parameterization will evolve throughout the pre-launch phase. The algorithm selection will take place little over one year before the launch in order to accommodate the finalization of the algorithm implementation and testing before the launch.

A timeline for preparation/data acquisition of in situ sites and networks is shown in the bottom part of the table. Some of the in situ sites are involved in the pre-launch field campaigns, and some in both pre- and post-launch campaigns, providing linkage between pre- and post-launch algorithm development, calibration and validation.

The operation of other relevant satellites is indicated on the last rows of the table, to show their general availability and opportunities for coordinated cal/val activities.

Table 5-1. Pre-launch Cal/Val Timeline (Draft without any commitments to dates)



5.3 Algorithm Issues

5.3.1 Sensor Algorithms

This Section provides a summary of those instrument pre-launch development, test and calibration activities (see [33] for detailed radiometer pre-launch calibration plan), which are essential to meeting the Level 1 product requirements.

5.3.1.1 Radiometer Brightness Temperature

The production of SMAP brightness temperatures is divided between producing the time-ordered calibrated brightness temperatures from the instrument output and gridding the brightness temperature to Earth grid.

5.3.1.1.1 Instrument Calibration

The radiometer pre-launch calibration is required to initialize the calibration algorithm, fill in specific thermal states of the thermal model, help post-launch calibration separate effects, and verify performance (reflector by analysis only). The objectives of the radiometer pre-launch calibration activities are to:

- provide initial values of calibration parameters (needed to run L1A and L1B algorithms and to meet performance requirements);
- provide temperature correction coefficients (needed to refine calibration parameters values once on orbit);
- provide full characterization of instrument behavior before launch, and
- show compatibility with the requirements and post-launch calibration scheme.

The calibration algorithm will be based on an analytical model describing the end-to-end system architecture employing parameters whose values are obtained from testing of the sub-systems. For sub-system level testing and characterization a noise source will be utilized. A heritage noise source (RATS) from Aquarius radiometer development can be utilized with some modifications. This noise source will also be utilized to verify the calibration repeatability requirement of 0.3 K. For verifying 3^{rd} and 4^{th} Stokes parameter functionality the Correlated Noise Calibration Standard (CNCS) will be utilized [34]. The radiometer calibration algorithm and parameters will be verified at the feed horn aperture through observation of the external references. A load cooled with liquid Nitrogen (LN2) will be used for the feed horn level verification (an LN2-load with 1 K brightness temperature uncertainty is available from Aquarius radiometer test campaign). The performance analysis, simulation and test conditions will be based on on-orbit environment scenarios.

The emissivity of the antenna reflector and the pattern of the antenna beam will be characterized in the pre-launch phase. These will be important calibration parameters affecting directly to the accuracy of the brightness temperature measurement and only partial verification/correction can be carried out from the orbit after the launch. The emissivity is determined using a sample of a mesh identical to the one used for the entire reflector. Due to the relatively low operating frequency the emissivity is projected to be very small, which is critical in mitigation of the effect of the changes in the physical temperature of the reflector. The antenna pattern is determined through a measurement of the feed horn pattern and the pattern of a 1-to-10 scale model of the reflector (TBC).

Additionally, in preparation for the post-launch calibration and validation activities, the suitability of several homogeneous areas on Earth's surface are investigated for use as external calibration references. The brightness temperature knowledge of these target areas need to allow calibration of the radiometer stability to 0.4 K. Potential target areas are Dome-C and Marie-Byrd in Antarctica and calm ocean surfaces (see Section 3.3.3). Studies predict 0.1 K stability for Dome-C and Marie-Byrd over an annual cycle [18],[19]. Dome-C area is being evaluated by European Space Agency's tower measurements [18]. An analysis using the tower and satellite data will be carried out to confirm the stability of Dome-C Radiative Transfer Model (RTM). Aquarius measurements over ocean buoys will be analyzed to establish the performance of the RTM over ocean surfaces. Also other regions will be investigated during the pre-launch activities. The Aquarius and SMOS L-band radiometer missions will provide new information on the suitability of all these regions.

A forward simulator will be developed to generate SMAP measured brightness temperatures. The simulator employs land and ocean surface parameters to calculate the Earth surface emission. The simulator will account for direct and reflected solar, lunar, galactic and CMB radiation; direct and reflected land, ocean and atmosphere radiation; Faraday rotation, and antenna pattern with sidelobes. The simulator will also include a radiometer model to simulate the behavior of the radiometer in the expected orbital conditions. The simulator will be used to study both radiometer calibration algorithm and geophysical algorithm performance. In the post-launch phase the simulator will be utilized for the correction of the antenna pattern.

5.3.1.1.2 Data Gridding

The baseline for the L1C_TB data product is for processing to a swath based grid co-registered with the L1C_S0_HiRes grid and processing to an Earth-fixed grid co-registered with L1C_S0_HiRes grid. Prototype SMAP-like data sets will be generated using simulated and actual satellite data (AMSR-E data scaled appropriately). These data will be used to study errors in adopting different gridding parameters - cell resolution, interpolation radius and weights. Gridding effects are especially noticeable at high contrast boundaries such as coastlines and lakes; therefore, Florida coastlines (TBC) will be used as a focus for these studies.

5.3.1.2 Radar Backscatter Cross Section

Radar pre-launch cal/val activities include characterization of the radar and its components. The purpose is to show the compatibility of the hardware with the requirements and also to support the post-launch calibration. These tests include among others propagation measurements, radiometric calibration of the receivers and characterization of the internal calibration procedures of the radar. Furthermore, performance analysis and simulations will be carried out based on instrument model and on-orbit environment scenarios. For the preparation of the post-launch external calibration suitable Earth targets will be surveyed. These targets are required to be large, uniform, isotropic, well-characterized and stable in order to be useful in the calibration process.

5.3.2 Geophysical Algorithms

5.3.2.1 Soil Moisture

Procedures will be developed to test the performance of the various candidate retrieval algorithms and quantify the expected error attributes of the ancillary data inputs. This information will assist in the selection of a baseline retrieval algorithm and in the generation of an error budget for the soil moisture products. The ancillary data will be available as part of SMAP Algorithm Testbed (see Section 5.4) and available for algorithm testing. The quality of this data will be assessed before evaluating its impact on the algorithm performance.

Of primary concern for the brightness temperature-based algorithms is the error in the effective soil temperature, since it requires the most frequent (daily) updates. The latency of the soil temperature input data is also important – currently NCEP produces a 6-hour temperature product, while ECMWF and GEOS/GMAO produce a 3-hour product. As part of the ancillary data preparation for ingestion into the soil moisture processing, a local 6 am soil temperature will be generated by interpolating in time between the closest available information.

Issues concerning the accuracy of vegetation parameterizations will be addressed in the context of ongoing field campaigns. These field experiments are expected to add to the growing database of historical information on microwave-vegetation relationships.

Existing ground and airborne radiometer and radar measurements will be used with the associated ground truth data to compare the accuracy of the various algorithms with each other. In general, the comparisons will involve the following steps:

- Inversion Accuracy: In this activity, each algorithm will be used to invert the same set of observational sensor data, and the results will be compared to in situ data. Since the range of surfaces for which measured airborne sensor data exist is limited, a model will be used to establish a database that covers the global surface soil moisture and roughness properties including RMS height, correlation length, and the forms of the correlation functions. The various retrieval algorithms will then be tested against this database to establish their accuracy, and the ranges of surface parameters over which they are applicable. This activity will be carried out on SDS Testbed as described in Section 5.4.1.

- The PALS airborne sensor (see Appendix C.1) L-band backscatter and brightness temperature fields are available at constant incidence angle as flight lines. PALS measurements were made in SGP99, SMEX02, CLASIC 2007 and SMAPVEX08 experiments. Although the radar and radiometer measurements are not at different resolutions, gridding and re-sampling can be performed to mimic SMAP instrument sampling. The UAVSAR (and earlier AIRSAR) airborne L-band backscatter data, collected in SMEX02 and CanEx-SM10 experiments, can also be utilized. UAVSAR offers fine resolution data that could be used for mimic SMAP instrument with PALS brightness temperature when measured coincidentally.

- SMOS brightness temperature based SMAP L2 radiometer soil moisture retrieval. The result will be compared to in situ sites and SMOS soil moisture products. A similar exercise will be carried out with Aquarius once it has been commissioned (latter half of 2011).

Before the SMAP launch, the L4_SM algorithm will be tested globally, to the extent possible, with satellite observations from the precursor missions discussed in Section 3.3.4. Among the pre-cursor missions, SMOS, the first passive microwave sensor operating at L-band, will play a key role. In each case, the outcome of the tests will be assessed by validating the assimilation estimates against in situ observations from existing networks and field experiments and by ensuring the consistency of internal diagnostics (see Post-launch validation). Existing long term network include SCAN, USCRN and FLUXNET networks in the North America region.

Additional development and testing for the L4 SM algorithm will be conducted in the context of Observing System Simulation Experiments (OSSE's; see section 4.1.4 of the L4_SM ATBD).

5.3.2.2 Freeze/Thaw

Freeze/thaw algorithm performance will be assessed using the SMAP SDS Algorithm Testbed (see Section 5.4.1) and available L-band microwave remote sensing datasets within the SMAP freeze/thaw domain, including satellite based observations from PALSAR and SMOS, and relatively fine scale remote sensing and biophysical data from in situ towers and airborne field campaigns, e.g. PALS (see Appendix C.1) and CARVE experiment (see Appendix D.1).

The algorithm results will be evaluated across regional gradients in climate, land cover, terrain and vegetation biomass through direct comparisons to existing surface biophysical measurement network observations including air/soil/vegetation temperature, snow depth and snow water-equivalent and eddy covariance CO_2 exchange. The relationship between the algorithm freeze/thaw state and the in situ sampling data will be established. Major focus areas include relations between the local/solar timing of satellite AM and PM overpasses and diurnal variability in local surface temperature and freeze/thaw state dynamics; the spatial and temporal distribution and stability of L-band radar backscatter under frozen and non-frozen conditions, and the effects of sub-grid scale land cover and topographic heterogeneity on the aggregate freeze/thaw signal within the sensor footprint.

Biophysical measurements from in situ station measurement networks will be used to drive physical models within the SMAP algorithm testbed for spatial and temporal extrapolation of land surface dielectric and radar backscatter properties and associated landscape freeze/thaw dynamics. These results will be compared with field campaign measurements and satellite based retrievals of these properties. Model sensitivity studies will be conducted to assess L3_FT algorithm and freeze/thaw classification uncertainties in response to uncertainties in sensor sigma-0 error and terrain and land cover heterogeneity within the sensor FOV.

5.3.2.3 Carbon Flux

Calibration and validation of the L4_C algorithms and products will involve model sensitivity studies in relation to observed variability in northern environmental conditions and uncertainties in satellite based GPP (e.g. MOD17) and L4_SM inputs (i.e., surface soil moisture and soil temperature). Model sensitivity studies will be conducted by perturbing input parameters within their respective ranges of uncertainty independently and in combination, and documenting L4_C algorithm responses.

Initialization and calibration of model parameters and initial SOC pools will be conducted prior to launch using available satellite GPP time series (e.g. MODIS MOD17) and long-term daily soil moisture and temperature inputs from the GMAO LIS. The accuracy of algorithm inputs and outputs will be established in relation to in situ CO_2 eddy flux measurements from regional tower networks (e.g., FLUXNET) and surface meteorological observations from regional weather stations following previously developed methods [41], [42], [43], [44]).

Calibration and optimization of L4_C algorithm parameters will be conducted using daily time series carbon fluxes from northern CO_2 eddy covariance flux towers (e.g. FLUXNET) representing regionally dominant vegetation classes. Monte Carlo Markov Chain (MCMC) optimization will be applied to minimize an objective function weighted by the observation error and model error covariance matrices by adjusting model decomposition rate constants and initial SOC pool sizes. Smaller values of the objective function are associated with more informative model-data configurations and resulting posterior distributions that allow for significance testing. The initial rate constants and SOC pools will be derived from regional soil inventories and published field studies, and compared with optimized parameter values. The initial SOC pools will also be compared to those estimated for steady state and average climate conditions and using optimized rate constants. This approach will provide quantitative and uncertainty estimates of the L4_C outputs relative to the tower observations.

5.4 SMAP SDS Testbed Role

SMAP Science Data System (SDS) Testbed will be utilized for algorithm development and testing, storing calibration and validation data, and carrying out calibration and validation of algorithms and products.

5.4.1 Testbed Simulations and Analysis

Simulation of retrieval algorithm performance is an important part of the pre-launch cal/val activities. The goals of the simulations are:

1) the identification of algorithm operational and performance issues over global diversity with the specified ancillary data, and
2) the parameterization and validation of the algorithms.

For meeting the first goal, simulated global observations with orbital instrument sampling are carried out on SMAP SDS Testbed. Figure 5-1 shows a schematic diagram on the processing flow on the testbed for science algorithm testing. The forward models of the instrument measurements include land surface model (Model Truth) and instrument characteristics (Orbit/Data Simulation, which feeds to Simulated Level 1 products). The retrieval algorithms are implemented as they would be on the operational system (Science Processing Prototype). The ancillary data identified in the ATBDs are made available on the testbed for full end-to-end retrieval algorithm runs.

For meeting the second goal actual, observational data is used on the testbed. This data will include coincidental in situ (Validation Data in Figure 5-1) and tower-based, airborne and spaceborne measurement data (Field Campaign Observations). The observational data is to cover wide range of diversity in terms of land cover conditions. The observations are reformatted to correspond to the Level 1 instrument data so that they can be fed to the same retrieval algorithms in the Science Processing Prototype as in the case of the global simulations. The use of the same processing establishes a critical link between the global simulations and actual observational data. The field campaign data sets are complemented with ancillary data of similar quality as that specified for the algorithms in the ATBDs of the products.

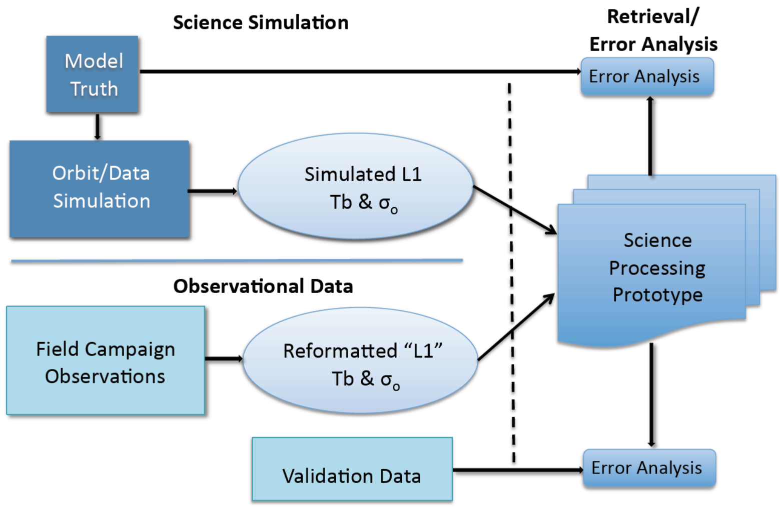


Figure 5-1: Diagram of the processing flow on the testbed for algorithm testing; both simulated orbit and land surface model data and actual observational data can be used as basis of the algorithm performance assessments.

5.4.2 Cal/Val Database

SMAP Cal/Val Database resides on the SMAP SDS Testbed. It contains the experimental data used for pre- and post-launch calibration and validation. The data from the utilized field experiments (see Sections 5.5 and 6.4), selected core sites (see Sections 5.6.3.3, 5.6.3.4 and 5.6.3.5) and sparse in situ networks (see Section 5.6.4.3) will be ingested into the database.

In the post launch phase the key feature of the database is allows automatic download and up-scaling of data from the selected in situ resources to the database for expedient processing against the SMAP products.

5.5 Pre-Launch Field Campaign Activities

In order to provide observational data for algorithm development, parameterization and validation, field campaigns employing in situ, tower-based, airborne, and spaceborne measurement systems will be utilized. In addition to activities designed in collaboration with SMAP, data from experiments sponsored by other missions and activities will be exploited if possible. This section summarizes pre-launch campaigns which have components matching the SMAP algorithm pre-launch needs. This set of campaigns will ensure that required data is available to complete the pre-launch validation of algorithms. Of particular significance is the SMAPVEX12 experiment, which is a campaign dedicated to resolve any outstanding (soil moisture) SMAP algorithm issues.

5.5.1 Remote Sensing Instrumentation Considerations

In the planning of the campaigns the availability of the supporting airborne and tower-based instruments must be considered. Since its inception, the SMAP Cal/Val Plan has supported the development of several key resources that included the tower-based active/passive ComRAD, the airborne PALS instrument and the airborne UAVSAR (see Appendix C). Over the past few years these instruments have been enhanced to improve the quality and utility of the data provided. In the case of ComRAD these improvements have include the antenna, calibration, and autonomous operation. For PALS, the major modification that is nearing completion was the ability to scan, which facilitates mapping large domains.

Looking toward the future, the PALS instrument and the UAVSAR platform are going to be heavily utilized by two projects under data used in previous campaigns as SMAP simulator, is going to be heavily utilized by the CARVE project between 2011 and 2015 (see Appendix D.1). Although, these deployments restrict the use of PALS they also open possibilities for economic opportunities for data collection. Another important resource for obtaining remotely sensed L-band radar signature is the UAVSAR airborne instrument (see Appendix C.2). UAVSAR is heavily utilized with several different research projects, and therefore, for insuring its availability the campaigns have to be planned well in advance. The other projects open also possibilities for additional deployments. A tower-based L-band radar-radiometer ComRAD (see Appendix C.3) will be available for deployments to gather stationary coincidental active and passive data.

5.5.2 Field Campaigns

5.5.2.1 SMAPVEX08 (East Coast, USA)

SMAPVEX08 was the first field campaigns dedicated to resolving SMAP algorithm issues took place on the East coast of US in the fall of 2008 ([45],[46]). In addition to the addressing open algorithm issues, the campaign had a major focus on questions related to RFI. Data from this campaign is being archived at TBD.

5.5.2.2 CanEx-SM10 (Canada)

NASA flew the airborne UAVSAR instrument in conjunction with the Canadian CanEx-SM10 SMOS soil moisture validation field experiment in Saskatchewan territory in June 2010 ([47],[48]). The campaign included airborne radiometer measurements and in situ sampling over four individual SMOS pixels (see Section 7.1.2 for more details).

5.5.2.3 SMAPEx 1-4 (Australia)

The University of Melbourne in Australia is organizing four week-long campaigns in 2010 and early 2011 designed to specifically address SMAP soil moisture algorithm issues ([49],[50]). The campaigns will include coincidental radiometer and radar measurement, which will provide contributions for the data set that can be used for the development of the active/passive soil moisture algorithm (see Section 7.1.1 for more details).

5.5.2.4 San Joaquin Valley Experiment (West Coast, USA)

The UAVSAR instrument will be deployed for San Joaquin Valley experiment on several days in 2010-2011 ([51],[52]). The primary objective of the experiment is to develop Vegetation Water Content (VWC) retrieval from optical remote sensing instruments. However, the experiment lends itself also for investigation of the effects of different types of vegetation on the radar-based soil moisture retrieval algorithm, since the experiment includes the UAVSAR instrument. Additional deployment of an airborne radiometer is also being investigated for experiment days in 2011, which would make it relevant also for the radiometer-based soil moisture retrieval algorithm and possibly the active-passive algorithm. The experiment sites include canopies of almond and pistachio trees (in addition to wheat and cotton), which provide relative rare opportunity to gather data from this type of landscape.

5.5.2.5 CARVE Opportunities (Alaska, USA)

Appendix D.1 summarizes the highlights of the CARVE experiment, which utilizes the PALS instrument (see Appendix C.1) to make L-band passive and active airborne measurements over many regions in Alaska. The deployment of PALS on Twin Otter is based out of Fairbanks, Alaska. The three campaigns are going to be executed annually in 2011 through 2015. The campaign provides an opportunity for SMAP to gather data over boreal landscapes which is being investigated. In principle, the CARVE observation could be augmented by denser in situ observations and more frequent over-flights.

5.5.2.6 ComRAD Deployments

NASA GSFC ComRAD (Combined Radar/Radiometer System) truck-based instrument [53] is going through a major upgrade improving its scan mechanism and antenna performance. The upgraded system will be tested in field conditions in March through April, 2011. After the performance has been validated in field conditions the instrument will be deployed in Maryland at OPE3 study site. The observations will include at least crop types at the site and will last until the fall 2011. The campaign will include enhanced observation to study the effects of morning dew on the soil moisture retrieval. Another long deployment is planned for 2012. The location is TBD (the SMAP ISST (see Section 5.6.1) site is one of the considered locations).

5.5.2.7 CanEx-FT11 (Canada)

The possibility of conducting freeze/thaw state field experiment in Canada with Canadian collaboration in the fall of 2011 and in the spring of 2012 is being examined. Details are being developed in cooperation with the Canadian Space Agency.

5.5.2.8 SMAPVEX12

A major soil moisture experiment SMAPVEX12 is being planned for summer 2012 to address the remaining algorithm issues before the launch. The general approach for organizing the campaign is to maximize the co-operation with other hydrology related research projects. Tentatively the primary L-band observations would be carried out by the PALS instrument (see Appendix C.1) as available from the CARVE campaign (see Section 5.5.2.5).

5.5.2.8.1 Algorithm Development

The location, land cover types, season and duration of the campaign are driven by the outstanding algorithm issues. At the moment the most significant soil moisture algorithm issues include retrieval under dense vegetation conditions, and changing vegetation, for all soil moisture algorithms; time series approach performance for L2_SM_A and L2_SM_AP, and diversity of the land cover of the available data for all soil moisture algorithms.

These would steer the campaign towards the end part of the growing season with relatively long duration of the campaign at locations including dense natural vegetation. The tentative plan for the campaign will be in place before SMAP Cal/Val workshop in May, 2011.

5.5.2.8.2 Validation Site Up-Scaling

It is planned that the SMAPVEX12 campaign will take place over at least one of the SMAP validation core sites. The airborne measurements over the site will be used to establish the up-scaling of the site, and also as input for the up-scaling methodology of all core sites.

5.5.2.8.3 End-to-End Cal/Val Exercise

The carrying out of the science cal/val of the mission during the Cal/Val Phase is a very time critical period. Once the correct operation of the spacecraft and observatory has been ensured in the IOC phase the validation of the science products may start. The validation of the geophysical retrievals (Level 2 products) requires combination of several data sources before carrying out the analysis. These data sources are very different from each other but the processing of each source has to be completed in a very short time so that the validation process, which does not only include comparison of data but adjustments of parameters and reprocessing runs of the data, can be completed in 12 months. The purpose of the Cal/Val exercise is to debug and streamline issues which may cause delays in this process.

Specifically, the end-to-end exercise aims to address the following issues:

- In situ networks:
    - Data transfers
    - Up-scaling processing to the SMAP resolutions
    - Data processing for match-up with the SMAP products
- Field campaign over a core site:
    - In situ data collection and processing
    - Airborne data collection and processing
    - Up-scaling processing to the SMAP resolutions
    - Data processing for match-up (in situ vs. airborne vs. satellite) with the SMAP products
- Other satellite data:
    - Data download
    - Scaling to the SMAP resolutions
    - Data processing for match-up with the SMAP products
- Retrieval algorithm response to the match-ups:
    - Adjustment of parameterization
    - Re-running retrieval algorithms

The rehearsal exercise is structured around the SMAPVEX12 field campaign. There will be a period, starting TBD weeks before the field campaign and ending TBD weeks after the field campaign, during which the data from in situ networks and other satellites are processed against simulated SMAP data. The simulated SMAP data will be produced as if the satellite was already in the orbit.

Special attention is paid on the field campaign in the middle of the exercise period. Field campaigns typically involve many different types of data sources by different participants. These include for example in situ sampling of different parameters, which require different amount of time for processing and calibration, various airborne instruments with different calibration processing, ancillary data on the geolocation in different formats for different data source and on the geographical location (such as soil texture and DEM). The exercise is used to test and debug this process using at least one of the sites.

The output of the exercise is collected in an evaluation report which is used to implement necessary changes in the processing chain of in situ network, field campaign and other satellite data.

5.6 Infrastructure Development for Validation

There are two key issues related to in situ measurements that will be resolved during the pre-launch phase of the Cal/Val Program: 1) inter-calibration between different sensors used in different in situ networks, and 2) up-scaling of the point-wise in situ measurement to the SMAP footprint scale. These efforts will be described in two subsequent sections.

5.6.1 Soil Moisture In Situ Sensor Testbed (SMAP-ISST)

A testbed will be established to test and calibrate various soil moisture probes provided by different manufacturers [54]. Specifically, the SMAP In Situ Sensor Testbed (ISST) will provide answers to the following set of questions: (1) How do different soil moisture sensors perform given the same hydrologic inputs of rainfall and evaporation? (2) How do different sampling intervals impact the soil moisture estimates, given instantaneous measurements versus time averaged measurements? (3) How do the orientations of installation influence the data record and effectiveness of the sensor? (4) How can networks which measure soil moisture by different fundamental methods, capacitance, FDR, TDR, reflectometry, be compared to a standard of gravimetric validation? (5) How can the measurements from different sensors with different sampling scales, particularly the COSMOS and GPS systems of soil moisture monitoring, compare given the variation in scale of measurement? Answering these questions is important for establishing a standard for soil moisture measurement in situ sites across the globe.

The site has been selected to be Marena in Oklahoma and it will be managed by Oklahoma State University (OSU) Range Research Station. The Oklahoma Mesonet MARE site is located 400 m from the site and two NOAA CRN stations are located nearby. The landscape of the site is characterized as rangeland and pasture. OSU Dept. Plant and Soil Science will provide additional local support.

The site consists of 4 separate sets of installations situated around Subsite A so they have radially increasing distance from Subsite A. Figure 5-2 shows the locations of the subsites: Subsite C is at a distance of 100 m, Subsite B at 200 m, Subsite D at 300 m and Mesonet MARE site additionally at a distance of 400 m from Subsite A.

Each subsite has a set of soil moisture sensors. Table 5-2 shows which sensors are installed at which subsite, number of sensors at each subsite and depths of the installations at those subsites. Passive Distributed Temperature Sensor System is installed between Subsites A and B. For investigation of the effect of the sampling interval each sensor is sampling with enhanced one-minute interval for five minutes every hour. Additionally, the vegetation water content, surface roughness and soil characteristics will be determined for the domain over the course of the experiment.

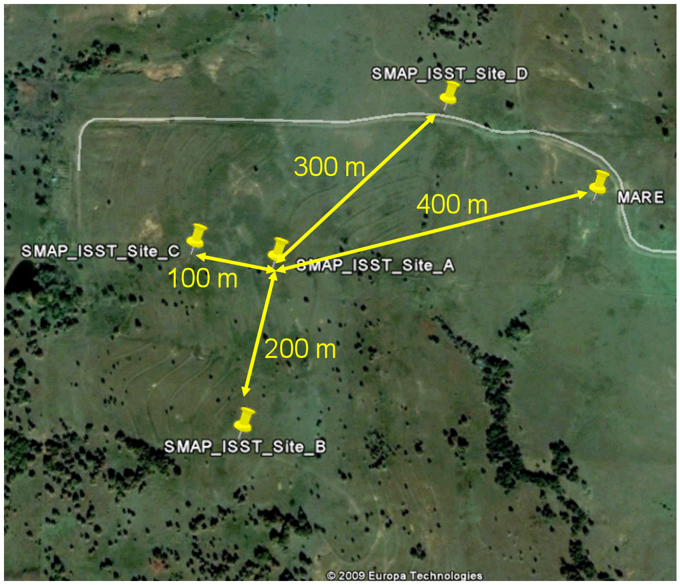


Figure 5-2. Geographic configuration of the SMAP ISST and its subsites.

Table 5-2. Soil moisture sensor types, subsites where they are installed, number of sensors per subsite, and depths of installations at those subsites.

Configuration	Sites	No.	Depths [cm]
Stevens Water Hydra Probes	A,B,C,D	6	2.5, 5, 10, 20, 50, 100
Delta-T Theta Probes	A,B,C,D	5	5, 10, 20, 50, 100
Decagon EC-TM probes	A,B,C,D	5	5, 10, 20, 50, 100
Sentek EnviroSMART	A,B,C,D	4	10 , 20, 50, 100
Acclima Sensor	A,B,C,D	5	5, 10, 20, 50, 100
Campbell CS 229-L heat dissipation sensors (OK Mesonet)	A,B,C,D	5	5, 10, 20, 50, 100
Campbell CS615/CS616 TDRs	A,B,C,D	5	5, 10, 20, 50, 100
Passive Distributed Temperature Sensor (DTS) System	A-B	1	10 cm
GPS reflectometers	A, C, D	1	
COSMOS system	A	1	
Climate Reference Network Station	B, D	6	2.5, 5
Traditional TDR System	A	4	5, 10, 50, 100
ASSH System (Mongolia)	A	TBD	

5.6.2 Soil Moisture Up-Scaling Study

As discussed in Section 3.3.1.2 up-scaling is a key issue in utilization of in situ measurements for calibration and validation. Therefore, one of the pre-launch cal/val objectives is to define a standard methodology on how to transfer point-wise ground measurements of in situ resources to SMAP footprint scale. There is a SDT working group focused on providing systematic scaling guidelines for the SMAP Cal/Val program.

The study starts with analysis of methodologies summarized in a public white paper put together by the working group. This analysis is then complemented and verified with a temporary in situ network (owned by USDA) deployed around selected measurement points. The pre-launch schedule in Table 5-1 shows the tentative timeline for these activities. The details of the methodology summary and the deployments of the temporary will be described as plans advance.

5.6.3 Core Validation Sites

Overall the highest priority in situ resources for SMAP Cal/Val are core validation sites. The scientific objective of these sites is to provide in situ observations that can be used to estimate soil moisture and/or freeze thaw accurately at the spatial resolution of the SMAP geophysical data products, while satisfying all the other requirements described in subsequent sections. An essential requirement is that the design includes multiple locations within a site that would provide a statistically reliable estimate. Furthermore, estimates of ground-truth sampling error must accompany the product area mean values.

Gaining access to resources located outside the U.S. should be considered. Depending upon the launch date of SMAP; the seasonal variations between the northern and southern hemispheres may impact the usefulness of some regions in validation. However, data access (included latency) and verification of calibration and scaling must be satisfied. In addition, there are some regions that are lacking in data and efforts should be made to promote the development of appropriate observing systems in these regions. The International Soil Moisture Working Group could be a means of engaging additional participation. Networks that cannot provide near-real time data will be of minor value in validation.

These sites will also be the focus of intensive ground and aircraft field campaigns to further verify scaling (see Section 6.4). Validation Core sites have been an important component of previous efforts to use remote sensing to estimate soil moisture (AMSR-E, SMOS) and other land parameters.

5.6.3.1 General Requirements for Core Sites

The following minimum criteria are desired for a core validation site:

- Accessible to researchers
- Has existing infrastructure including access and utilities
- Heritage of scientific studies to build from
- Long term commitment by the sponsor/host
- An area that is homogeneous or has a uniform mixture of land covers at the product scale
- Represents an extensive or important biome
- Complements the overall set of sites

In situ methods provide point observations and each point is orders of magnitude different from satellite grid products. A variety of techniques can be used to establish the scaling of the points and grids (see Section 3.3.1.2). Each participating validation site will have associated a description of the methods that will be used to scale their in situ measurements up to a SMAP grid cell size. The data from each core site will be automatically downloaded to the SMAP Cal/Val Database (see Section 5.4.2).

5.6.3.2 Selection Process for Core Sites

The core sites are selected through a proposal process. Both U.S. and international investigators may propose that their in situ resource will be used for a SMAP product calibration and validation as a core site. The NSPIRES www-portal of NASA will be used for publishing the solicitation and collecting the proposals. The solicitation will be out by TBD and the selection is made by TBD. A second round of selection is also considered (TBD).

The ATBD requirements for the core validation sites (Sections 4.2 and 4.3) are augmented by the general requirements given above (Section 5.6.3.1).

5.6.3.3 Soil Moisture Core Sites (Level 2 and 4 products)

Table 5-3 lists the core validation sites selected as described in Section 5.6.3.2 once the process has been completed.

Table 5-3. List of soil moisture core validation sites and applicability to resolution and depth

Site	Location	Resolution [km]			Depth [cm]	
		36	9	3	5	100
TBD						

5.6.3.4 Freeze/Thaw Core Sites (Level 3 product)

Table 5-4 lists the core validation sites selected as described in Section 5.6.3.2 once the process has been completed.

Table 5-4. List of freeze/thaw core validation sites

Site	Location	Biome
TBD		

5.6.3.5 NEE Core Sites (Level 4 product)

Table 5-5 lists the core validation sites selected as described in Section 5.6.3.2 once the process has been completed.

Table 5-5. List of NEE core validation sites

Site	Location	Biome
TBD		

5.6.4 Sparse In Situ Networks

5.6.4.1 General Requirements for Sparse Networks

The following minimum criteria are desired for sparse networks utilized in the calibration and validation efforts:

- Accessible to researchers
- Long term commitment by the sponsor/host
- Available in a timely manner
- Compatible with the validation requirements in terms of depths, etc.

In situ methods provide point observations and each point is orders of magnitude different from satellite grid products. A variety of techniques can be used to establish the scaling of the points and grids (see Section 3.3.1.2). Each participating validation site will have associated a description of the methods that will be used to scale their in situ measurements up to a SMAP grid cell size. Additionally, whenever there is doubt about the validity of a data point or a part of the time series, the measurements in question will be excluded and that no data be filled in or interpolated.

Dealing with the scaling of these sparse networks to SMAP product footprints will likely be a responsibility for the SMAP project.

5.6.4.2 Selection Process

The sparse in situ networks (see Section 3.3.1) for SMAP product validation are selected based on availability, quality and need for coverage. This means that all network data available to SMAP Project will be considered, and they will be prioritized based on the quality and coverage area. The selected data will be automatically downloaded to SMAP Cal/Val Database (see Section 5.4.2) for further processing. The ATBD requirements for the soil moisture sparse networks (Sections 4.2 and 4.3) are augmented by the general requirements given above (Section 5.6.4.1).

5.6.4.3 List of Sparse Networks

Table 5-6 lists the sparse networks selected as described in Section 5.6.4.2 above.

Table 5-6. List of selected sparse in situ networks.

Network	Location	Number of sites included	5 cm	100 cm	F/T	NEE
SCAN	Continental US	177 (TBC)	x	x		
USCRN	Continental US	191 (TBC)	x	x		
NEON	Continental US	20 (TBC)	x			
ALECTRA	Alaska	8 (TBC)			x	
FLUXNET	TBD	TBD				x
Oklahoma Mesonet	Oklahoma	127 (TBC)	x	x		
-TBD-						

6 POST-LAUNCH ACTIVITIES

6.1 Overview

In the post-launch period the calibration and validation activities will address directly the measurement requirements for the L1-L4 data products. Each data product has quantifiable performance specifications to be met over the mission lifetime, with calibration and validation requirements addressed in their respective ATBDs.

Post-launch calibration and validation activities are divided into four main parts following the IOC phase after launch:

(1) Release of beta (or provisional) versions of L1 and L2 products

(2) Six-month sensor product Cal/Val phase, after which delivery of validated L1 products to the public archive will begin.

(3) Twelve-month geophysical product Cal/Val phase, after which delivery of validated L2 through L4 products to the public archive will begin.

(4) Extended monitoring phase (routine science operations) lasting for the remainder of the science mission. During this period, additional algorithm upgrades and reprocessing of data products can be implemented if found necessary (e.g., as a result of drifts or anomalies discovered during analysis of the science products).

6.2 Post-Launch Cal/Val Timeline

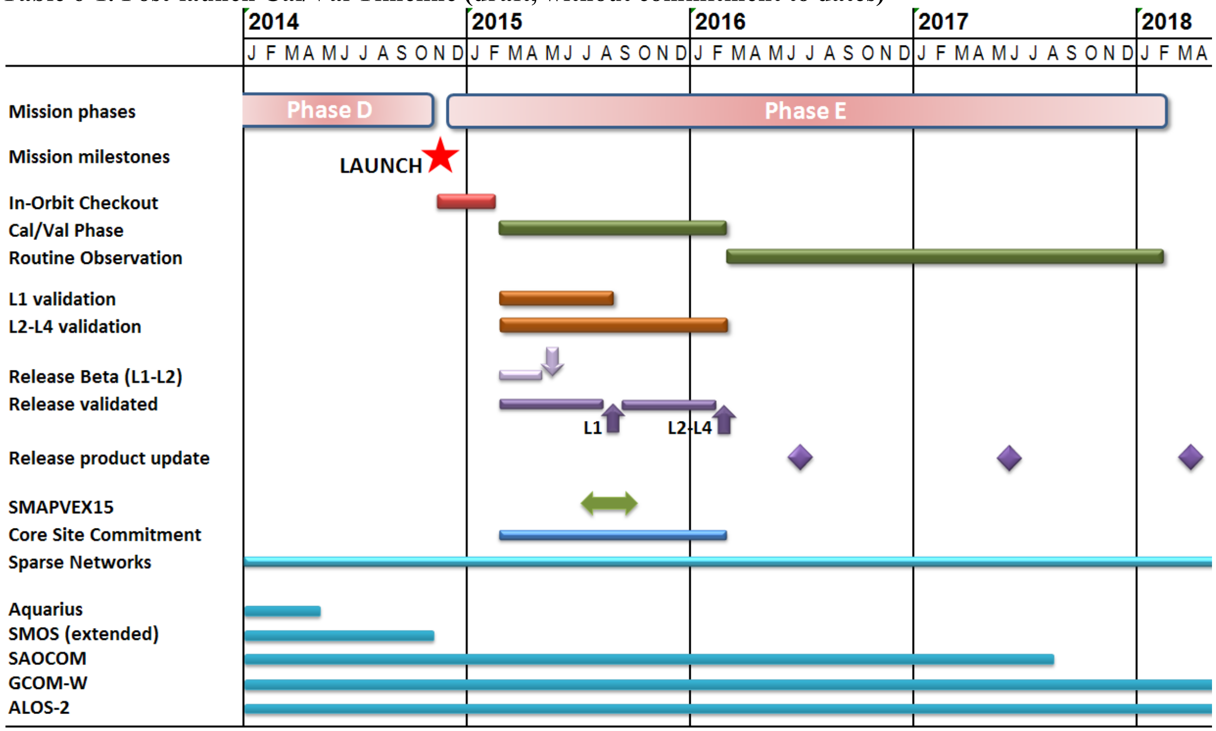
Table 6-1 shows the draft timeline (placeholders, and without commitment to dates) for the Cal/Val in the post-launch phase (Phase E). The timeline shows the key Cal/Val activities and relevant project schedule items. Phase E of the mission is divided into the IOC phase, Science Cal/Val phase, and Routine Operations phase as discussed in Section 2.6. This is reflected at the top of the table. In the Cal/Val Phase there are two important milestones: (1) release of validated L0 and L1 data, and (2) release of validated L2 through L4 data.

In situ validation sites, networks and field campaigns are the core of the science product cal/val in the post-launch phase. The table highlights the operation and occurrence of these.

Coordination of post-launch Cal/Val and Science Data System (SDS) activities is important since the SDS produces the science products, provides storage and management of Cal/Val data, provides data analysis tools, and performs reprocessing and metadata generation of algorithm and product versions. The Level 2 requirements state that the cumulative mission science data shall be reprocessed up to three times (if necessary) to improve the data quality and that the final reprocessing shall be used to generate consistently-processed set for the complete mission one month after the end of prime (3-year) science mission. The table shows placeholders for these milestones.

Finally, the table displays other relevant satellite missions taking place simultaneously with the SMAP mission.

Table 6-1. Post-launch Cal/Val Timeline (draft, without commitment to dates)



6.3 Mission Products

6.3.1 Sensor Products

6.3.1.1 Radiometer Brightness Temperature

The calibration approach of the SMAP radiometer requires that the absolute calibration is done on orbit after launch. The specific objectives of the radiometer post-launch calibration and validation activities are following:

- Provide any necessary tuning of pre-launch calibration, including bias removal, and set calibration-related parameters that can only be determined on-orbit
- Calibrate drifts in the measured brightness temperature
- Validate instrument performance i.e. determine radiometer performance figures
- Validate brightness temperature product i.e. determine overall uncertainty
- Validate brightness temperature gridding to Earth grid

The following subsections break these objectives down to separable components of the radiometer operation and calibration.

6.3.1.1.1 Absolute Brightness Temperature Calibration

The calibration of the brightness temperature measured by the radiometer is based on the pre-launch characterization of the instrument and measurement of external beam-filling targets. These targets include sites in Antarctica (Dome-C, Marie-Byrd, etc), ocean, and the Cosmic Microwave Background (CMB) which is measured in Cold Sky Calibration (CSC) maneuver. In CSC the instrument is pointed at the galactic pole. The maneuver will be carried out monthly (TBC)..

Inter-satellite calibration will also be employed if other L-band radiometer instruments will be available, such as SMOS and Aquarius.

6.3.1.1.2 Geolocation

Standard geolocation techniques which have been previously developed and inherited from other missions (e.g. QuikSCAT, AIRS) are carefully documented in existing documents. These algorithms account for spacecraft position, pointing, and attitude; antenna scan angle; curvature of Earth and measurement timing.

The baseline geolocation will be established based on the space craft ephemeris and the nominal scan geometry. The measured brightness temperatures will be utilized in several ways to refine the baseline. Flat targets, such as large open ocean regions, can be used to determine pitch and roll bias utilizing the measured brightness temperature over the full 360° scan. The scan cone angle can also be solved and used to adjust the nominal cone angel. Alignment of coastlines and water bodies can be used to determine the best fit of the two-dimensional brightness temperature image vs. known geography. Coastline crossings can be also be utilized but the scan position needs to be addressed (as opposed to the case of fixed beam instruments such as Aquarius). Finally, the radiometer geolocation can be compared against the SAR geolocation, which, however, needs to account for the latency in the processing.

6.3.1.1.3 Faraday Rotation Correction

The validation of the Faraday rotation correction will be accomplished by comparing the estimated Faraday rotation with the Faraday rotation obtained from ionosphere electron density (International Reference Ionosphere (IRI) database) and magnetic field data (International Geomagnetic Reference Field (IGRF) database). The rotation angle can also be compared with the estimation by SMOS [55]. This validation will be particularly important for calibration data collected over the ocean, where 3^{rd} Stokes parameter is generated both by Faraday rotation and by the azimuthal asymmetry of ocean wave fields, although ocean-generated third Stokes parameter is expected to be less than 1K.

6.3.1.1.4 Atmospheric Correction

The effect of atmosphere is expected to be very small at L-band. Nevertheless, a correction will be applied to the brightness temperature measurement. The atmospheric correction will be carried out by applying global temperature and humidity profiles (from forecast data) to radiative transfer model of standard clear-sky case, at least over ocean. Over land an application of path delay measured by other microwave instruments is considered to improve accuracy.

6.3.1.1.5 Antenna Pattern Correction

The SMAP Brightness Temperature Forward Simulator (see Section 5.3.1.1) will be used to calculate an estimate of the effect of the sidelobes on the brightness temperature. The method will be validated utilizing known scenes.

6.3.1.1.6 RFI and Post-Launch Calibration

For validation of RFI mitigation, RFI detection flags will be compared with known RFI sites (such as FAA radars) and aircraft underpasses. The SMAP brightness temperature product will be compared with brightness temperature products of the Aquarius and SMOS missions (at about 40° incidence angle) and also the RFI detection flags will be compared with the RFI records generated by Aquarius and SMOS. RFI mitigation can also be validated by comparing soil moisture retrieval quality measures to RFI detection flags; poor retrieval quality could be due to missed RFI.

6.3.1.1.7 Drift Monitoring and Correction

The validation activity of the brightness temperature ensures that the L1B_TB product meets its requirement. In this activity several homogeneous regions, whose brightness temperature is accurately known, are used to adjust the brightness temperature produced by the radiometer with stability of less than 0.4 K over long period of time (as opposed to near-instantaneous calibration addressed in Section 6.3.1.1.1).

Potential targets are Dome-C and Marie-Byrd area in Antarctica and calm ocean surfaces (see Section 3.3.3). Studies predict 0.1-K stability for Dome-C and Marie-Byrd in brightness temperature over an annual cycle [18], [19]. Radiative transfer model (RTM) of calm ocean surfaces with buoy measurements (such as TOGA-TAO and ARGO arrays) and regional averages based on environmental reanalysis models is expected to satisfy the accuracy requirements. The RTMs used for the calibration and validation account also for atmospheric effects, reflections of celestial objects, etc. where applicable. The suitability of the target areas and their RTMs will be confirmed in pre-launch activities (see Section 5.3.1.1.1).

Besides absolute calibration, the CSC output may also be used to track inter-seasonal changes in the calibration coefficients; however the thermal changes in the instrument during the CSC maneuver need to be accurately accounted for.

6.3.1.1.8 Validation of Gridding

The accuracy of the gridding algorithms will be evaluated by viewing coastlines, islands, and inland lakes.

6.3.1.2 Radar Backscatter Cross Section

The post-launch calibration goals for the radar measured backscatter cross section are to remove channel-to-channel and pixel-to-pixel biases to the required accuracy and to remove the absolute bias to the required accuracy. The goal of the cross section validation is to show that the requirements of L1_S0_LoRes and L1_S0_HiRes have been met and also to use this information to optimize the accuracy of the final cross section products.

The post-launch external calibration of the radar receive and transmit operation consists of several components. It is expected that man-made targets are insufficient to complete the calibration. This is due to the fact that the pixel size is too large for corner reflectors (however, they are cheap and may be helpful in geo-location validation) and the transponder accuracy is insufficient. Instead, the CSC maneuver and pre-launch calibration parameters are used for the receiver characterization and statistical analysis of large, uniform, isotropic and well-characterized, stable scenes (such as Amazon) are applied. Additionally, cross-calibrations with other contemporaneously flying radars are used. These possibly include ALOS-2, Aquarius and UAVSAR measurements over distributed targets and over targets where these comparison sensors can be calibrated with corner reflectors. Furthermore, calibrations based on natural targets have been demonstrated be very accurate. For example, JPL Ku-Band scatterometers removed channel-to-channel and pixel-to-pixel biases to 0.2 dB, and JERS-1 demonstrated that Amazon is stable to less than 0.2 dB at L-Band. The polarimetric backscatter reciprocity can also be utilized in the calibration. Finally, active mode data integrity checks can be carried out using BFPQ statistics, spectrum check, zero range delay check, and internal loop-back measurements can be processed to look for proper chirp operation and check transmit power stability.

For calibrating the SAR image formation, checks for scan oriented brightness variation (scalloping) indicating antenna, attitude, and/or ephemeris offsets will be carried out. The processing parameters can be tweaked and attitude from the radar data can be derived as needed.

In terms of mitigating the RFI problem occasional receive only data collections will be carried out in order to survey the RFI conditions and flag problematic areas.

6.3.2 Geophysical Products

This Section describes the post-launch calibration and validation of the geophysical products, L2-L4. Note that the cal/val of L2 soil moisture products automatically calibrates and validates the L3 soil moisture products, since they are just compilations of L2 products.

6.3.2.1 Soil Moisture Passive (L2/3_SM_P)

The baseline validation will be a comparison of retrievals at 36 km with ground-based observations that have been verified as providing a spatial average of soil moisture at this scale (see Section 5.6.2). However, other types of observations or products will contribute to post-launch validation. The following subsections describe:

- Long-term measurement networks, including dense sampling sites and sparse networks
- Field experiments that will provide moderate-term intensive measurements of soil moisture and other surface characteristics at SMAP footprint scales
- Algorithm tests against other satellite products
- Hydrologic modeling to generate soil moisture products using assimilated data independent of SMAP data

6.3.2.1.1 Long-Term Soil Moisture Measurement Networks

The usefulness of soil moisture in situ networks for satellite product validation was described in Section 3.3.1. The ATBD of the radiometer-based soil moisture product identified core validation sites (see Section 5.6.3) as the most significant resource for its validation [35]. The list of soil moisture 36-km resolution core sites is presented in Section 5.6.3.3, following selection. The core validation sites will be complemented by the sparse networks. The list of sparse networks soil moisture 36-km resolution is presented in Section 5.6.4.3 following selection.

The soil moisture measurements of these networks will be up-scaled and compared with the radiometer-based soil moisture products. First comparisons will be made before the release of the beta release. The full comparison and evaluation will be completed by the end of Cal/Val Phase. The comparison between the in situ estimates and the product will also be used to refine the algorithm and its parameterization.

The validation metric (mean of site-specific RMSE, see [8]) is determined separately for sparse networks and core sites due to their different up-scaling properties.

6.3.2.1.2 Soil Moisture Field Experiments with Radiometer

The role of the airborne field experiments for satellite product validation was described in Section 3.3.1.1. These experiments provide critical information that can be used to independently assess the contributions of radiometer calibration, algorithm structure and parameterization, and scaling on performance. Furthermore, they provide moderate-term intensive measurements of soil moisture and other surface characteristics at 36-km pixel scales. Due to the large pixel size of the L2_SM_P product airborne field experiments, which map an entire pixel, are especially valuable as they help to resolve the heterogeneity properties of the product pixel area.

SMAPVEX15 field experiment is planned to include airborne radiometer observations. While SMAPVEX15 is scheduled as soon as possible after launch, the uncertainties of the actual date, the relationship to the season, and other logistics require that time-wise commitments for utilization of the campaign data be conservative. Therefore, SMAPVEX15 and other potential field experiments shall be used as part of the more robust validation of the SMAP products. SMAPVEX15 and other post-launch field campaigns are discussed more in Section 6.4. The analysis will focus on matching up airborne observation with satellite products and produce RMSE on product scale and also regarding variability within the product footprint.

The field experiment data will be processed and analyzed for the final validation report. The beta release will not include results from the field experiments not only due to the processing time but also due to the timing of the campaign which cannot be guaranteed to take place within three months after completion of the IOC.

6.3.2.1.3 Tests Against Other Satellite Products

The usability of other satellite products for the validation of a satellite product was described in Section 3.3.4. Depending upon mission timing and life, it is possible that both SMOS and GCOM-W will be producing global soil moisture products at the same time as SMAP. In Section 5.3.2.1, the use of SMOS data prior to the launch of SMAP was described. The radiometer-based soil moisture product will be compared with soil moisture products of SMOS and GCOM-W. This provides reference sources over a wide range of conditions.

Assessments will be conducted to estimate, monitor, and correct bias offsets between SMAP products and SMOS and GCOM-W products where justified by additional guidance by in situ measurements or model data.

The first tests against SMOS and GCOM-W soil moisture products and the ASCAT soil moisture index will be performed by the end of Cal/Val Phase, and the monitoring will continue as long as these products are available. They are not a priority for the beta release.

6.3.2.1.4 Comparisons to Independent Hydrologic Models

The utilization of model based techniques for satellite product validation was described in Section 3.3.5. This effort involves both forward modeling of brightness temperatures and inversions for soil moisture using models and data assimilation products. Offsets between SMAP algorithm products and these other data may be due to sensor absolute calibration errors or to errors in parameters of the models. Algorithm analyses will permit adjustment of the brightness temperatures computed by the models (used in the retrieval algorithm) to the SMAP product values.

Hydrologic modeling will be performed to generate soil moisture products at larger (basin-wide and continental) scales using assimilated data independent of SMAP data. The resulting soil moisture fields will be compared with SMAP soil moisture over diurnal and seasonal cycles. The model-derived soil moisture fields can be used to extend the comparisons to larger space and time domains.

The model-based analysis will be carried out by the end of the Cal/Val Phase. It is not a priority for the beta release.

6.3.2.1.5 Combining Different Validation Sources

Each abovementioned validation component produces a separate quantified validation result. The primary, and most emphasized, value is given by the core sites, which is complemented by the result from the sparse networks to add coverage and diversity of validation conditions. The field campaign results will be used to augment this value by giving additional insight to the breakdown of error sources of in situ measurements and scaling process.

The role of other satellite products is to establish the product relative to these products and will not directly add to the validity of the product. The result from the hydrologic models will be used to compute additional error metrics (such as correlation) assuming that RMSE of the model is on the comparable order in comparison with the in situ results.

The beta release will include only assessment based on selection of core sites and sparse networks. The validation release will include input from all validation sources.

6.3.2.2 Soil Moisture Active (L2/3_SM_A)

The baseline validation will be a comparison of retrievals at 3 km with ground-based observations that have been verified as providing a spatial average of soil moisture at this scale (see Section 5.6.2). However, other types of observations or products will contribute to post-launch validation. The validation approach of the L2_SM_A product follows that of the L2_SM_P: the scaling issue is only adjusted to the finer 3-km resolution and there are some issues which require different amount of attention due to the different observing instrument (radar as opposed to radiometer). The following subsections discuss the use of long term measurement networks, field experiments, utilization of other satellite products, and hydrological modeling for the radar-based soil moisture product validation.

6.3.2.2.1 Long-Term Soil Moisture Measurement Networks

The usefulness of soil moisture in situ networks for satellite product validation was described in Section 3.3.1. In terms of utilization of in situ core sites and the sparse networks the L2_SM_A product validation follows mostly the approach of the L2_SM_P product. However, the scaling process of the point measurements (see Section 3.3.1.2) has different parameters, since the pixel size of the L2_SM_A product is only 3 km (see Section 5.6.2). The list of soil moisture 3-km resolution core sites is presented in Section 5.6.3.3, when selected. The core validation sites will be complemented by the sparse networks. The list of soil moisture 3-km resolution sparse networks is presented in Section 5.6.4.3, when selected.

The soil moisture measurements of these networks will be up-scaled and compared with the radiometer-based soil moisture products. First comparisons will be made before the release of the beta release. The full comparison and evaluation will be completed by the end of Cal/Val Phase. The comparison between the in situ estimates and the product will also be used to refine the algorithm and its parameterization.

The validation metric (mean of site-specific RMSE, see [8]) is determined separately for sparse networks and core sites due to their different up-scaling properties.

6.3.2.2.2 Soil Moisture Field Experiments with Radar

The role of the airborne field experiments for satellite product validation was described in Section 3.3.1.1. Similarly as in the case of L2_SM_P the field experiments provide critical information that can be used to independently assess the contributions of radar calibration, algorithm structure and parameterization, and scaling on performance for the L2_SM_A product validation. They provide moderate-term intensive measurements of soil moisture and other surface characteristics at L2_SM_A pixel scales. However, due to the relatively small pixel size of the L2_SM_A product the significance of the airborne field experiments in terms of scaling properties of a pixel is not as disparate as in the case of L2_SM_P (36-km pixel).

SMAPVEX15 is planned to include airborne radar observations. While SMAPVEX15 is scheduled as soon as possible after launch, the uncertainties of the actual date, the relationship to the season, and other logistics require that time-wise commitments for utilization of the campaign data be conservative. Therefore, SMAPVEX15 and other potential field experiments shall be used as part of the more robust validation of the SMAP products. SMAPVEX15 and other post-launch field campaigns are discussed more in Section 6.4. The analysis will focus on matching up airborne observation with satellite products and produce RMSE on product scale and also regarding variability within the product footprint.

The field experiment data will be processed and analyzed for the final validation report. The beta release will not include results from the field experiments not only due to the processing time but also due to the timing of the campaign which cannot be guaranteed to take place within three months after completion of the IOC.

6.3.2.2.3 Tests Against Other Satellite Products

The utility of other satellite products for the validation of a SMAP product was described in Section 3.3.4. Radar cross section measured by ALOS PALSAR (or ALOS-2) and SAOCOM may be obtained to test the algorithms. The resolutions of these radars are very high, which can be utilized in the validation of the mitigation of pixel heterogeneity effects. However, care must be taken regarding the various polarimetric modes and incidence angles of PALSAR and SAOCOM. Assessments will be conducted to estimate, monitor, and correct bias offsets between SMAP products and ALOS-2 and SAOCOM products over the validation sites.

The first tests against SAOCOM soil moisture products will be performed by the end of Cal/Val Phase, and the monitoring will continue as long as these products are available. They are not a priority for the beta release.

6.3.2.2.4 Comparisons to Independent Hydrologic Models

The utilization of model based techniques for satellite product validation was described in Section 3.3.5. Hydrologic modeling will be performed to generate soil moisture products at larger (basin-wide and continental) scales using assimilated data independent of SMAP data. The resulting soil moisture fields will be compared with SMAP soil moisture over diurnal and seasonal cycles. The model-derived soil moisture fields can be used to extend the comparisons to larger space and time domains.

The model-based analysis will be carried out by the end of the Cal/Val Phase. It is not a priority for the beta release.

6.3.2.2.5 Combining Different Validation Sources

Each abovementioned validation component produces a separate quantified validation result. The primary, and most emphasized, value is given by the core sites, which is complemented by the result from the sparse networks to add coverage and diversity of validation conditions. The field campaign results will be used to augment this value by giving additional insight to the breakdown of error sources in in situ measurements and scaling process.

The role of other satellite products is to establish the product relative to these products and will not directly add to the validity of the product. The result from the hydrologic models will be used to compute additional error metrics (such as correlation) assuming that RMSE of the model is on the comparable order in comparison with the in situ results.

The beta release will include only assessment based on selection of core sites and sparse networks. The validation release will include input from all validation sources.

6.3.2.3 Soil Moisture Active/Passive (L2/3_SM_AP)

The baseline validation will be a comparison of retrievals at 9 km with ground-based observations that have been verified as providing a spatial average of soil moisture at this scale. However, other types of observations or products will contribute to the post-launch validation. The validation approach of the L2_SM_AP product takes into account the validation efforts of both L2_SM_P and L2_SM_A, as L2_SM_AP combines both radiometer and radar measurements for retrieval. The following subsections discuss use of long term measurement networks, field experiments, utilization of other satellite products and hydrological modeling.

6.3.2.3.1 Long-Term Soil Moisture Measurement Networks

The utility of soil moisture in situ networks for satellite product validation was described in Section 3.3.1. The utilization of in situ dense sampling sites and sparse networks for the L2_SM_AP product validation mostly follows the approach of the L2_SM_P product. However, the scaling process of the point measurements has different parameters, since the pixel size of the L2_SM_AP product is only 9 km and the pixel is formed by a combination of 36 km radiometer pixels and 3 km radar pixels. The list of soil moisture 9-km resolution core sites is presented in Section 5.6.3.3. The core validation sites will be complemented by the sparse networks. The list of soil moisture 9-km resolution sparse networks is presented in Section 5.6.4.3 when selected.

The soil moisture measurements of these networks will be up-scaled and compared with the radiometer-based soil moisture products. First comparisons will be made before the release of the beta release. The full comparison and evaluation will be completed by the end of Cal/Val Phase. The comparison between the in situ estimates and the product will also be used to refine the algorithm and its parameterization.

The validation metric (mean of site-specific RMSE, see [8]) is determined separately for sparse networks and core sites due to their different up-scaling properties.

6.3.2.3.2 Soil Moisture Field Experiments with Radar and Radiometer Combination

The role of the airborne field experiments for satellite product validation was described in Section 3.3.1.1. Similarly as in the case of L2_SM_P the field experiments provide critical information that can be used to independently assess the contributions of radar and radiometer calibration, algorithm structure and parameterization, and scaling on performance for the L2_SM_AP product validation. They provide moderate-term intensive measurements of soil moisture and other surface characteristics at L2_SM_AP pixel scales. The collection of field experiment data is combined for all soil moisture algorithms to campaigns occurring as has been laid out for L2_SM_P in Section 6.3.2.1.2 and summarized in Section 6.4.

SMAPVEX15 is planned to include combined airborne radar and radiometer observations. While SMAPVEX15 is scheduled as soon as possible after launch, the uncertainties of the actual date, the relationship to the season, and other logistics require that time-wise commitments for utilization of the campaign data be conservative. Therefore, SMAPVEX15 and other potential field experiments shall be used as part of the more robust validation of the SMAP products. SMAPVEX15 and other post-launch field campaigns are discussed more in Section 6.4. The analysis will focus on matching up airborne observation with satellite products and produce RMSE on product scale and also regarding variability within the product footprint.

The field experiment data will be processed and analyzed for the final validation report. The beta release will not include results from the field experiments not only due to the processing time but also due to the timing of the campaign which cannot be guaranteed to take place within three months after completion of the IOC.

6.3.2.4 Tests Against Other Satellite Products

The utility of other satellite products for the validation of a satellite product was described in Section 3.3.4. The testing of the L2_SM_AP directly with other satellite data products is limited due to the unique nature of combining L-band radiometer and L-band radar with synthetic aperture processing. However, it may be possible to carry out some algorithm level tests by combining data from L-band radiometers (such as SMOS) and L-band radar (such as ALOS-2) flying on different platforms. The direct comparisons of soil moisture products on a 9-km scale can be carried out against SAOCOM by aggregating its soil moisture products.

The first tests against these other satellite products will be performed by the end of Cal/Val Phase, and the monitoring will continue as long as these products are available. They are not a priority for the beta release.

6.3.2.4.1 Comparisons to Independent Hydrologic Models

The utilization of model based techniques for satellite product validation was described in Section 3.3.5. Hydrologic modeling will be performed to generate soil moisture products at larger (basin-wide and continental) scales using assimilated data independent of SMAP data. The resulting soil moisture fields will be compared with SMAP soil moisture over diurnal and seasonal cycles. The model-derived soil moisture fields can be used to extend the comparisons to larger space and time domains.

The model-based analysis will be carried out by the end of the Cal/Val Phase. It is not a priority for the beta release.

6.3.2.4.2 Combining Different Validation Sources

Each abovementioned validation component produces a separate quantified validation result. The primary, and most emphasized, value is given by the core sites, which is complemented by the result from the sparse networks to add coverage and diversity of validation conditions. The field campaign results will be used to augment this value by giving additional insight to the breakdown of error sources in in situ measurements and scaling process.

The role of other satellite products is to establish the product relative to these products and will not directly add to the validity of the product. The result from the hydrologic models will be used to compute additional error metrics (such as correlation) assuming that RMSE of the model is on the comparable order in comparison with the in situ results.

The beta release will include only assessment based on selection of core sites and sparse networks. The validation release will include input from all validation sources.

6.3.2.5 Freeze/Thaw State (L3_FT_A)

The baseline validation will be a comparison of freeze/thaw state retrievals with ground-based observations that have been verified as providing a spatial average of freeze/thaw state at this scale. However, other types of observations or products will contribute to the post-launch validation. The following subsections discuss the use of long-term measurement networks and field experiments.

6.3.2.5.1 Long-Term In Situ Measurement Networks

Success criteria for the L3_FT_A product will be assessed relative to in situ network measurements of frozen and non-frozen status for northern (≥45°N) biophysical monitoring stations within the major land cover and climate regimes. The list of freeze/thaw core sites is presented in Section 5.6.3.4. The core validation sites will be complemented by the sparse networks. The list of freeze/thaw state sparse networks is presented in Section 5.6.4.3.

In situ frozen/non-frozen status will be determined as a composite ensemble of vegetation, soil and air temperature measurements, and will be compared to coincident footprint scale L3 freeze/thaw measurements. The fulfillment of the requirements will be assessed by comparing SMAP freeze/thaw classification results and in situ frozen or non-frozen status.

The soil moisture measurements of these networks will be up-scaled and compared with the radiometer-based soil moisture products. The full comparison and evaluation will be completed by the end of Cal/Val Phase. The comparison between the in situ estimates and the product will also be used to refine the algorithm and its parameterization.

6.3.2.5.2 Field Experiments with Radar

Additional L3 freeze/thaw validation activities may involve field campaigns using relatively fine scale airborne (e.g., PALS) and tower based L-band remote sensing in conjunction with detailed biophysical measurements from in situ station networks (e.g., FLUXNET). Particular focus areas for these activities include examining sub-grid scale spatial heterogeneity in radar backscatter and freeze/thaw characteristics within the SMAP footprint; verifying spatial and temporal stability in L-band radar backscatter for reference frozen and non-frozen conditions; verifying linkages between L3 freeze/thaw dynamics, vegetation productivity and seasonal patterns in land-atmosphere CO_2 exchange. The results of these validation activities may then be used to refine pre-launch algorithms and ancillary data sets to improve L3 freeze/thaw product accuracy.

6.3.2.5.3 Combining Different Validation Sources

Each abovementioned validation component produces a separate quantified validation result. The primary, and most emphasized, value is given by the core sites, which is complemented by the result from the sparse networks to add coverage and diversity of validation conditions. The field campaign results will be used to augment this value by giving additional insight to the breakdown of error sources in in situ measurements and scaling process.

6.3.2.6 Soil Moisture Data Assimilation Product (L4_SM)

For certain applications, such as the initialization of soil moisture reservoirs in atmospheric forecasting systems, the absolute error in the soil moisture estimates is not necessarily relevant [56]. Since scaling of soil moisture data is required prior to their use in model-based applications, time-invariant biases in the moments of the L4_SM product become meaningless. For model applications, the temporal correlation of soil moisture estimates with independent observations is therefore a more relevant validation metric. By focusing on the correlation metric, evaluation problems stemming from the inconsistency between point and area-averaged quantities are, to some extent, ameliorated. [57] provide a detailed discussion of the relationship between RMSE and correlation metrics.

6.3.2.6.1 Validation with In Situ Observations

Validation of the *surface* soil moisture estimates from the L4_SM product against in situ observations will be identical to that of the L2_SM_A/P surface soil moisture product including validation against measurements from dedicated field experiments (Section 6.3.2.3).

The *root zone* soil moisture estimates of the L4_SM product will be validated with in situ observations from existing operational ground-based networks which are listed in Sections 5.6.3.3 and 0..

Land surface flux, surface temperature, and other estimates from the L4_SM product will be evaluated against in situ observations as much as possible but will be considered research products. The availability of land surface flux data for validation is very limited. A comparably large collection of such data is provided free of charge by the Coordinated Energy and Water Cycle Observations Project (CEOP; http://www.ceop.net) and will be used to validate the data assimilation products. From 1 October 2002 through 31 December 2004, for example, 24 CEOP reference sites, located mostly in Kansas and Oklahoma, provide hourly surface flux data that is sufficient for validation.

6.3.2.6.2 Validation with Internal Assimilation Diagnostics

Relative to the coverage of the satellite and model soil moisture estimates, few in situ data are available. The soil moisture data assimilation system produces internal diagnostics that will be used to indirectly validate its output. Specifically, the statistics of appropriately normalized innovations will be examined ([58]; see also discussion of adaptive filtering in Section 4.1.2 of the L4_SM ATBD).

6.3.2.6.3 Validation with High-Quality, Independent Precipitation Observations

Validation with in situ soil moisture observations is difficult because there are few long-term station observations and because there is a mismatch between the point-scale of the in situ measurements and the distributed (10 km) scale of the L4_SM product. Compared to ground-based soil moisture probes, rain gauges are inexpensive, easy to maintain, and have already been widely installed over vast continental regions. Moreover, variability in daily rainfall accumulations occurs at spatial scales that are typically coarser than the fine-scale (potentially < 10 m) variability of soil moisture. Because errors in soil moisture are primarily a result of errors in precipitation, and because precipitation observations are more abundant and reflective of more appropriate scales, gauge-based precipitation observations can be used for an indirect evaluation of soil moisture estimates.

[27] developed a data assimilation-based approach for evaluating surface soil moisture retrievals that effectively substitutes rain gauge measurements for ground-based soil moisture observations. The approach is based on evaluating the correlation coefficient between antecedent rainfall error and analysis increments that are produced by the soil moisture assimilation system. The use of rain gauge observations expands potential soil moisture validation locations from isolated sites (Figure 1) to continental-scale regions over which high-quality rain gauge measurements are available. A

modified form of this approach was used to evaluate the added value of AMSR-E based soil moisture retrievals for root-zone soil moisture monitoring within the continental United States [59]. The approach will be applied to evaluate the increments that are produced by the L4_SM algorithm.

The fulfillment of the root-zone soil moisture requirement will be assessed by comparing SMAP L4_SM results with TBD data set of soil moisture estimates.

6.3.2.7 NEE Product (L4_C)

The statistical methods and domains of validity envisaged for testing the L4_C algorithms and for demonstrating that their performance meets the SMAP science requirements will involve direct comparisons between model outputs and tower eddy covariance CO_2 flux measurements from northern FLUXNET tower sites [60]. Similar protocols have been successfully implemented for validating the MODIS MOD17 GPP products ([41], [61], [62], [63]). The L4_C performance and error budgets will also be determined through model perturbation and sensitivity analyses spanning the range of observed northern environmental conditions and using model input accuracy information. If the L4_C algorithms are implemented within the GMAO assimilation framework, this will enable robust error tracking and quantification of the value of SMAP inputs relative to L4_C calculations derived solely from unconstrained model reanalysis inputs. The model reanalysis framework will also enable L4_C products to be generated well before initiation of the SMAP data stream and will provide a standard from which improved model calculations using SMAP derived inputs can be assessed.

L4_C model parameters and initial SOC pool sizes will be determined prior to launch through model simulations and sensitivity studies using GMAO LIS assimilation based soil moisture and temperature inputs and MODIS GPP inputs over the observed range of Northern Hemisphere ($\geq$45 °N) variability. These estimates will be refined post-launch following initiation of the SMAP data stream and associated production of the input GMAO L4_SM fields. If the L4_C algorithms are implemented within the GMAO assimilation framework, the value of SMAP inputs will be quantified relative to L4_C NEE calculations derived solely from unconstrained model reanalysis inputs.

The accuracy of the L4_C outputs, including NEE and component carbon fluxes for GPP and R_{tot} will be also be established in relation to in situ CO_2 eddy flux measurements and associated carbon budgets from northern tower networks (e.g., FLUXNET) within regionally dominant vegetation classes following established protocols (e.g. [41], [43]).

The fulfillment of the NEE requirement will be assessed by comparing SMAP L4_C NEE output with FLUXNET NEE estimates.

6.4 Dedicated Post-Launch Field Campaigns

The purpose of the post-launch field campaigns is to provide critical information needed for the validation of the products. Each product identified a strategy for the validation in the preceding sections and whether field campaigns are required to carry out this strategy. This section presents a summary of coordinated efforts which answer these needs of each product.

Field experiments typically require considerable coordination between different groups, such as the project team, SDT working groups, government agencies, research institutions and universities. This imposes relatively long lead time for the planning of campaigns and may affect the timing of the campaign. At the same time, the field campaigns need to be finished well before the end of the Cal/Val Phase to leave time for processing and analysis. Moreover, there is also optimum seasonal timing to carry out soil moisture and freeze/thaw state field campaigns.

6.4.1 SMAPVEX15

A field campaign dedicated to calibration and validation of SMAP soil moisture products is planned to be carried out in North-America after the completion of IOC (but no later than IOC+8 months to allow time for data processing and analysis before the end of the Cal/Val Phase) depending on the launch date.

Considering the launch date of November 2014 (which would mean the end of IOC in February 2015) the campaign would be carried out in May to October timeframe in 2015 to coincide with favorable season for soil moisture validation. The location of the campaign is TBD but it will be carried out over one or several of the soil moisture core validation sites (see Section 5.6.3.3).

The airborne instrumentation will include at least airborne L-band radar and radiometer; possibly PALS and UAVSAR (see Appendices C.1 and C.2). The planning needs to account for the CARVE and AirMOSS projects (see Appendices D.1and D.2), which utilize these airborne resources as well.

The aim of the campaign is to capture a range of soil moisture and vegetation conditions and this is accounted for in the timing and planning of the location of the campaign.

The in situ sampling needs to account for the different sensitivities of the radiometer and radar algorithms on different surface and vegetation components. Since the radar is more sensitive to these parameters, the requirements of the radar-based algorithms are driving the design.

7 INTERNATIONAL COLLABORATION

This Section summarizes projects and associated observing networks have already made commitments to supporting the SMAP Cal/Val program.

International collaboration in SMAP Cal/Val consists of in situ observations in the Core Validation Site program (after selection) or sparse networks, field campaigns that provide pre- and/or post-launch sensor and geophysical observations, and satellite-based observations and products. Satellite program interactions are described in Appendix E. The plans for in situ observations have been discussed previously; therefore, only the field experiment and satellite elements are described here.

7.1 Pre-Launch Field Campaigns

7.1.1 SMAPEx campaigns in Australia in 2010-2011

The University of Melbourne and University of Monash, under support from the Australian Research Council, are carrying out field experiments with airborne passive and active L-band instrumentation, which will contribute to the pre-launch algorithm development of SMAP [49],[50]. The campaigns are called Soil Moisture Active Passive Experiments (SMAPEx). The campaigns are scheduled to take place in July 2010, December 2010, March 2011 and October 2011 (the exact dates of the last two are TBC). The objective of the campaigns is to develop algorithms for accurate high resolution soil moisture mapping under Australian conditions that will subsequently be used by the next generation soil moisture satellite mission of NASA, known as SMAP.

The concept for the study is to obtain SMAP simulator data in each of the four seasons to build a robust data set for grazing and agricultural land covers. The length of each campaign is one week. Figure 7-1 shows the location and ground truth sites of the planned study region. The Yanco area lies within the Murrumbidgee catchment in southeast Australia.

The study site has been used in previous campaigns and in situ sites provide continuous observations of soil moisture. The site instrumentation has been modified to match up with the multiple scales required for validation of all SMAP soil moisture products and as result it also matches the Core Validation Site requirements described in Section 5.6.3. During the field campaign intensive ground-based sampling is conducted to support the algorithm development studies as well as providing calibration and scaling information on the in situ network.

The airborne microwave instruments to be used in the campaign will include Polarimetric L-band Multibeam Radiometer (PLMR) and Polarimetric L-band Imaging Synthetic Aperture Radar (PLIS). The configuration allows simultaneous radiometer footprints of 1 km and radar footprints of 10 m when flown at flying altitude of 3000 m.

The ground observations will be publicly available at a website of the University of Melbourne [50]. Data from the airborne instruments will be made available to the SMAP validation community.

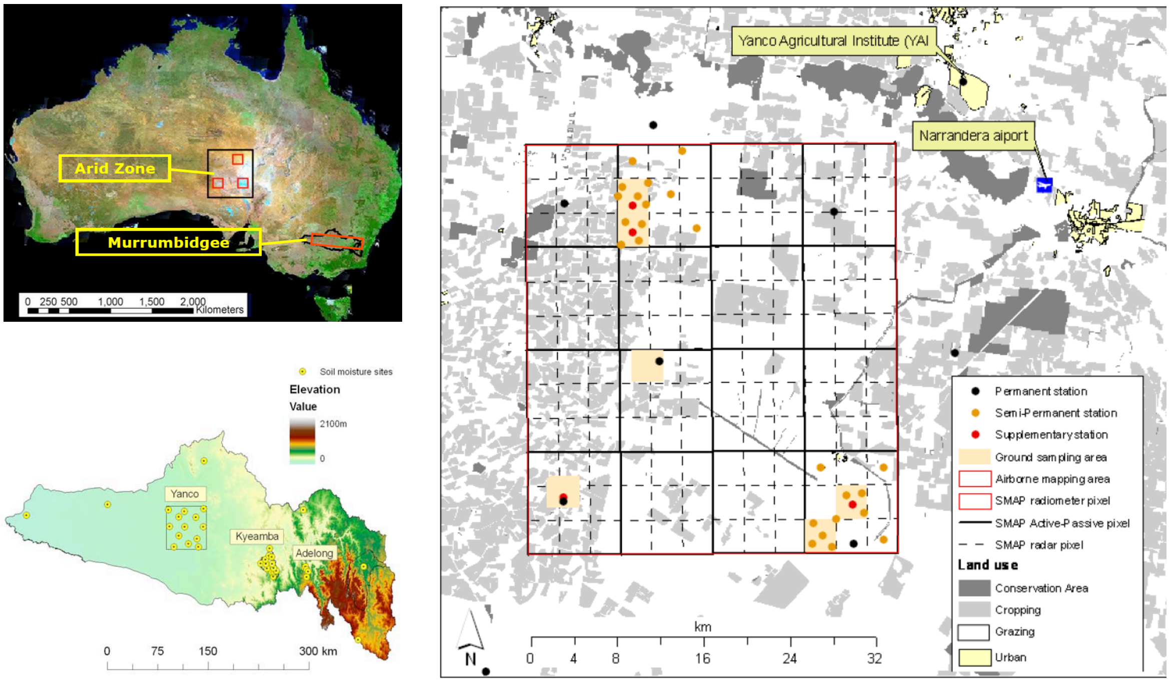


Figure 7-1. Australia and the location of the Murrumbidgee catchment (upper left), the location of the Yanco study region in the Murrumbidgee catchment (lower left) and the Yanco study area with the locations of continuous soil moisture monitoring and intensive ground sampling sites with expected SMAP grid (on the right).

7.1.2 CanEx-SM10 (Canada)

The Canadian Space Agency is a partner in the SMAP project and as part of its collaboration is providing support to Canadian institutions to collect both in situ and field campaign data for algorithm development and validation. The first activity was a soil moisture field campaign named Canadian Experiment for Soil Moisture 2010 (CanEx-SM10) that was carried out in Saskatchewan, Canada, from June 2 to June 16, 2010 [47],[48]. This was an enhancement of a planned effort to contribute to the validation of Soil Moisture and Ocean Salinity (SMOS) soil moisture estimation and brightness temperature products. Additional ground and aircraft observations were added to support the pre-launch soil moisture algorithm calibration and validation of SMAP over agricultural and forested sites. The specific objectives were:

- Comparative analysis of L-Band microwave data along with field measurements;
- Development of soil moisture retrieval algorithms from passive and active microwave data (SMOS, RADARSAT-2, ALOS-PALSAR, L-Band airborne data from EC’s radiometer and NASA’s UAVSAR);
- Scaling methodologies for SMOS coarse resolution data,
- Calibration and scaling of two potential Core Validation Sites including two nested in situ soil moisture networks, and
- Assimilation of SMOS data in land surface systems to improve land surface initial conditions provided to environmental forecast models.

Two experiment sites were selected for the campaign. One is an agricultural area located in the south of Saskatoon, near Kenaston, Saskatchewan and the second is a forested area located at about

100 km north-east of Prince Albert, Saskatchewan (see Figure 7-2). They are located at about 300 km from each other. Measurements from these two sites provide analysis of soil moisture over large areas of very different types of soil and vegetation.

Ground sampling over the experiment sites included intensive soil moisture, vegetation and roughness measurements. Additionally, enhanced vegetation sampling was carried out at the BERMS site. Longer term in situ measurement were initiated over the BERMS site to establish the scaling of the limited permanent sites. At the Kenaston site, there were two nested networks, one operated by EC and the other by the University of Guelph, which matched many of the criteria for a Core Validation Site.

Simultaneous with the ground measurements and SMOS overpasses, aircraft campaigns were conducted over the Kenaston and BERMS sites. The airborne microwave instruments included an L-band radiometer from Environment Canada on the Canadian NRC Twin Otter and an L-band synthetic aperture (UAVSAR) on NASA G-III aircraft (see Appendix C.2).

The campaign focused first on the Kenaston site over a period of about two weeks including 6 days of flights with the radiometer and radar and 1 day of flights with the radar only. At the end of the campaign, one day of sampling including both radiometer and radar over the BERMS site.

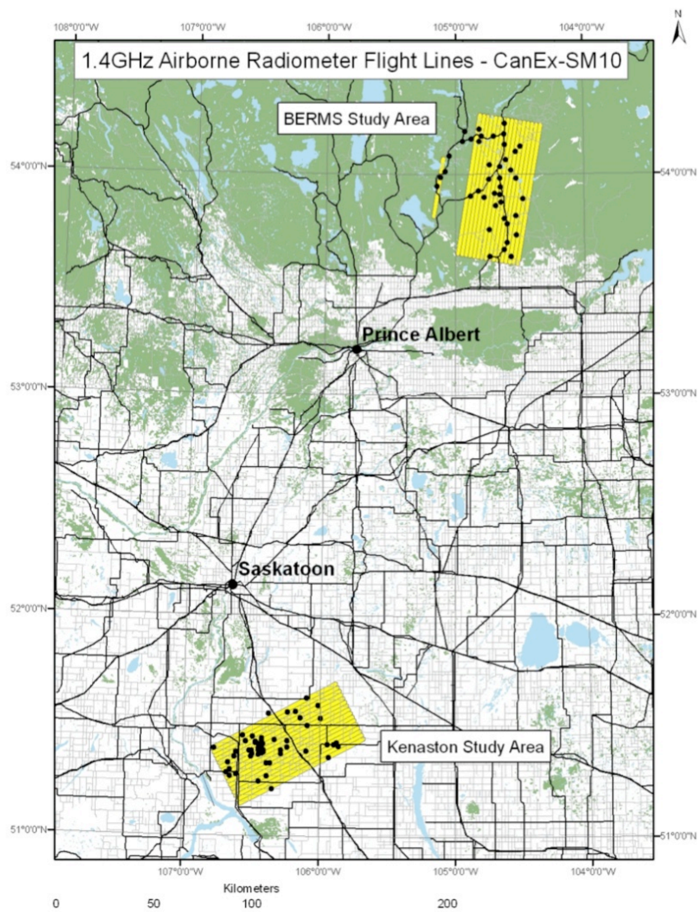


Figure 7-2. CanEx-SM10 experiment sites.

7.1.3 CanEx-FT11 (Canada)

As a complement to the successful soil moisture campaign, SMAP and CSA have initiated planning for a freeze/thaw experiment over the Quebec region in Canada in the fall of 2011 and possibly the spring of 2012 to capture freezing and thawing events with airborne L-band radar and radiometer. Details of this campaign should be available in the spring of 2011.

7.2 Post-Launch Field Campaigns

It is anticipated that the collaborations described above for pre-launch will continue into post-launch; however, no details have been developed at this stage.

7.3 Satellite Data

7.3.1 SMOS

ESA provides data from missions such as SMOS through an ongoing proposal process. The SMOS project has initiated a proposal for acquisition of SMOS data (specifically Level 1c and Level 2 SM) that includes the archive and global coverage throughout the SMOS mission life.

7.3.2 GCOM-W

JAXA has provided data from its missions to NASA in the past. At the present, there are ongoing discussions between NASA and JAXA that are specifically related to GCOM-W that include the AMSR-2 instrument. If these are not formalized by the time of the GCOM-W launch, the SMAP project will attempt to establish scientific collaboration directly in order to acquire soil moisture products. It is also possible that the current NASA AMSR-E program algorithms may be adapted for GCOM-W to continue this data stream.

7.3.3 SAOCOM

SAOCOM will provide data to groups based upon a proposal process. CONAE released a pre-launch announcement of opportunity that the SMAP project responded to. When the post-launch announcement of opportunity is released, the SMAP project will submit a proposal for the acquisition of data to support Cal/Val.

8 SMAP SDT CALIBRATION & VALIDATION WORKING GROUP

The SMAP project initiated Working Groups (WGs) as a means to enable broad science participation in the SMAP mission. The working groups are led by Science Definition Team (SDT) members and provide forums for information exchange on issues related to SMAP science and applications goals and objectives. A specific WG was created to support SMAP Cal/Val. Community participation and contributions to the Cal/Val Working Group (CVWG) will contribute to designing the Cal/Val program and generating a plan. It provides a mechanism for engaging key people and teams that can contribute to resolving pre-launch algorithm issues, infrastructure for validation, and the post-launch validation.

Cal/Val involves all mission products; from sensor data to L4 value added. Supporting these involves a wide range of elements including in situ, tower and aircraft simulators, satellite observations, model and surrogate variables, and field campaigns. As a result the CVWG requires the participation of a large and diverse group of scientists and disciplines.

Some aspects of SMAP Cal/Val are unique to SMAP while others would be enhanced through coordination with other satellite mission Cal/Val programs, for example those of SMOS and GCOM-W. The CVWG provides one mechanism for engaging scientists and activities involved in these missions and leveraging their resources.

CVWG activities are carried out mainly through emails and teleconferences. The primary forum for interaction will be a series of Cal/Val Workshops conducted at key points during the pre-launch and post-launch phases (approximately every eighteen months).

Workshops to Date

June 9-11, 2009 (Oxnard, CA). This workshop was organized jointly by the SMAP CVWG and the SMAP Algorithm Working Group (AWG). The workshop was open to the science community and attracted approximately 80 attendees, including international participants from Europe, Asia, and Australia. The workshop provided a forum for the science community to review the status of algorithm development for SMAP data products and to provide input to the development of the science data calibration and validation plan. Overview presentations covered the SMAP science objectives and requirements, project status, the measurement system, the science data system, and the algorithm testbed. Presentations were also given on each of the data product algorithms, and participants had the opportunity to provide feedback on the algorithm plans and to make brief presentations of their own work on related algorithm topics. In the calibration and validation portion of the workshop, presentations described the major in situ soil moisture networks and measurement techniques including the U.S. Department of Agriculture Soil Climate Analysis Network (SCAN), National Oceanic and Atmospheric Administration Climate Reference Network (CRN), Oklahoma Mesonet, U.S. Department of Agriculture/Agricultural Research Service watersheds, Cosmic- ray Soil Moisture Observing System (COSMOS), Global Positioning System (GPS), and others. The workshop presentations can be viewed through the Algorithms & Cal/Val Workshop link on the SMAP Web page [68].

May 3-5, 2011 (Oxnard, CA). During the pre-launch phase, the focus of Cal/Val is on contributing to algorithm development and establishing the infrastructure for post-launch validation. As a result of the preliminary Cal/Val plan and previous workshop involving the science community, activities were initiated to support the objectives of Cal/Val. These included field campaigns to provide specific data sets for the algorithm teams, developing tower and aircraft-based simulators, and developing and implementing methods for integrating the diverse in situ resources available for validation. As part of this workshop, results to date will be reviewed and additional requirements identified. These activities include additional field campaigns. Specific topics to be addressed at the workshop include:

- New programmatic commitments in the NASA aircraft program will impact SMAP field campaign planning and need to be integrated.
- SMOS will have been in operation for over one-year. Lessons learned in its Cal/Val program will benefit SMAP planning.
- A robust in situ Cal/Val program will require partnerships with a variety of research groups and programs around the world. A mechanism for achieving this and agreement on standards must be established. To support this topic, the members of the GEWEX International Soil Moisture Working Group, the CEOP Land Products Validation-Soil Moisture Group, and the International Soil Moisture Network will be invited to participate in the workshop.

The participation of the broad science community and the plans and decisions arising from discussions of these issues will have significance for identifying research needs and allocating resources. Details are available at [69].

9 REFERENCES

[1] Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond", National Research Council, 2007.

[2] Science Requirements and Mission Success Criteria, SMAP Mission.

[3] "SMAP Science Workshop", Arlington, VA, July 9-10, 2007; "SMAP Open Meeting at IGARSS 2008", Boston, MA, July 6, 2008; "Microwave Land Hydrology Workshop", Oxnard, CA, October 20-22, 2008.

[4] D. Entekhabi, E. Wood, "Science Rationale for SMAP Baseline and Minimum Missions", Version 2, SMAP Science Transition Team, June 6, 2008.

[5] WWW: Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV): http://calvalportal.ceos.org/CalValPortal/welcome.do

[6] WWW: Land Products Sub-Group of Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV): http://lpvs.gsfc.nasa.gov

[7] SMAP Science Terms and Definitions, Draft, 2010.

[8] R. Reichle et al., "Skill Metrics for Validation of SMAP Data Products", SMAP SDT Memo, April 13, 2010.

[9] WWW: International Soil Moisture Network: http://www.ipf.tuwien.ac.at/insitu/

[10] J. H. Dane, C. Topp, "Methods of Soil Analysis. Part 4. Physical Methods", Soil Science Society of America Book Series, Vol. 5, 2002.

[11] Vachaud, G., A. Passerat De Silans, P. Balabanis, M. Vauclin, "Temporal Stability of Spatially Measured Soil Water Probability Density Function", Soil Science Society of America J., Vol. 49 No. 4, pp. 822-828, 1985.

[12] Cosh, M. H., T. J. Jackson, R. Bindlish, J. H. Prueger, "Watershed Scale Temporal and Spatial Stability of Soil Moisture and Its Role in Validating Satellite Estimates", Remote Sensing of Environment, Vol. 92, pp. 427-435, 2004.

[13] Famiglietti, J. S., D. Ryu, A. A. Berg, M. Rodell, T. J. Jackson, "Field Observations of Soil Moisture Variability Across Scales", Water Resources Research Vol. 44, W01423, 2008.

[14] Crow, W. T, D. Ryu, J. S. Famiglietti, "Upscaling of Field-Scale Soil Moisture Measurements Using Distributed Land Surface Modeling", Remote Sensing of Environment, Vo. 28, pp. 1-14, 2005.

[15] P. O'Neill, T. Jackson, D. Entekhabi, E. Njoku, "Survey of L-Band Tower and Airborne Sensor Systems Relevant to Upcoming Soil Moisture Missions", IEEE Geosci. Remote Sensing Society Newsletter, June 2009.

[16] Floury, N., M. Drinkwater, O. Witasse, "L-band Brightness Temperature of Ice Sheets in Antarctica: Emission Modeling Ionospheric Contribution and Temporal Stability", Proc. IEEE International Geoscience and Remote Sensing Symposium 2002, Toronto, Canada, June 24-28, 2002.

[17] Drinkwater, M., M. Brogioni, G. Macelloni, P. Pampaloni, E. Santi, 2007, "DOME-C Multi-frequency Microwave Characterization and Related Campaign Activities", 7th SMOS Workshop (http://earth.esa.int/smos07), Frascati, Italy, October 29-31, 2007.

[18] Paloscia, S., G. Macelloni, M. Brogioni, S. Pettinato, M. Drinkwater, A. Crepaz, 2009, "DOMEX-2: Long Time-Stability of L-Band Emission at Dome-C Antarctica", SMOS Validation & Retrieval Team Readiness Review Workshop (http://earth.esa.int/smos09/), Lisbon, Portugal, March 11-13, 2009.

[19] S. Misra, S. Brown, "Modeling of Microwave Emissions from the Marie-Byrd Antarctic Region: A Stable Calibration Target in the L-band", Presentation at Jet Propulsion Laboratory, California Institute of Technology, August 26, 2010.

[20] Kennett, R. G., F. K. Li, "Seasat Over-Land Scatterometer Data, Part II: Selection of Extended Area Land-Target Sites For the Calibration of Spaceborne Scatterometers", IEEE Trans. Geosci. Remote Sens., Vol. 27, No. 6, 1989.

[21] Brown, S. T., C. Ruf, 2003, "On-Orbit Microwave Blackbody Calibration Using Regions of Dense Vegetation", Proc. IEEE International Geoscience and Remote Sensing Symposium 2003, Toulouse, France, July 21-25, 2003.

[22] Atlas, R., R. N. Hoffman, J. Ardizzone, M. Leidner, J. C. Jusen, "A New Cross-Calibrated, Multi Ocean Surface Wind Product", Proc. IEEE International Geoscience and Remote Sensing Symposium 2008, Boston, MA, USA, July 6-11, 2008.

[23] Kunz, L. B., D. G. Long, "Calibrating SeaWinds and QuikSCAT Scatterometers Using Natural Land Targets", IEEE Geosci. Remote Sens. Letters, Vol. 2, No. 2, 2005.

[24] Liu, J., X. Zhan, T. J. Jackson, "Soil Moisture Retrieval from WindSat Using the Single Channel Algorithm Toward a Blended Global Soil Moisture Product from Multiple Microwave Sensors", Proc. SPIE 2008, Vol. 7085, 2008.

[25] Jackson, T., "SMAP Soil Moisture Overpass Time Considerations," SMAP Workshop Report, NASA, 2007.

[26] K. Scipal, T. Holmes, R. de Jeu, V. Naeimi, W. Wagner, "A Possible Solution for the Problem of Estimating the Error Structure of Global Soil Moisture Data Set", Geophys. Res. Let., Vol. 35, 2008.

[27] Crow, W. T., and X. W. Zhan, Continental-scale evaluation of remotely sensed soil moisture products, IEEE Trans. Geosci. Remote. Sens., Vol. 45, No. 4, pp. 451-455, 2007.

[28] W. T. Crow, "A Novel Method for Quantifying Value in Spaceborne Soil Moisture Retrievals", J. Hydrometeorol., Vol. 8, 2007.

[29] J. Piepmeier et al., "L1B_TB ATBD", Preliminary, September 15, 2010.

[30] E. Njoku et al., "L1C_TB ATBD", Preliminary, September 15, 2010.

[31] R. West et al., "L1B_S0_LoRes ATBD", Preliminary, September 15, 2010.

[32] R. West et al., "L1C_S0_HiRes ATBD", Preliminary, September 15, 2010.

[33] D. Hudson, J. Peng, "SMAP Radiometer (minus reflector) Pre-Launch Calibration Plan", NASA Goddard Space Flight Center, September 8, 2010.

[34] J. Peng, C. S. Ruf, "Calibration Method for Fully Polarimetric Microwave Radiometers Using the Correlated Noise Calibration Standard", IEEE Trans. Geosci. Remote Sens., Vol. 46, No. 10, October 2008.

[35] P. O'Neill et al, "L2/3_SM_P ATBD", Preliminary, September 15, 2010.

[36] J. van Zyl et al, "L2/3_SM_A ATBD", Preliminary, September 15, 2010.

[37] D. Entekhabi et al., "L2/3_SM_AP ATBD", Preliminary, September 15, 2010.

[38] K. McDonald et al., "L3_FT_A ATBD", Preliminary, September 15, 2010.

[39] R. Reichle et al., "L4_SM ATBD", Preliminary, September 15, 2010.

[40] J. Kimball et al., "L4_C ATBD", Preliminary, September 15, 2010.

[41] F. A. Heinsch, M. Zhao, S.W. Running, J.S. Kimball, R.R. Nemani, et al., "Evaluation of remote sensing based terrestrial productivity from MODIS using regional tower eddy flux network observations", IEEE Trans. Geosci. Remote Sens., Vol. 44, No. 7, pp. 1908-1925, 2006.

[42] Jones, L.A., J.S. Kimball, K.C. McDonald, S.K. Chan, E.G., Njoku, and W.C. Oechel, "Satellite microwave remote sensing of boreal and arctic soil temperatures from AMSR-E", IEEE Trans. Geosci. Remote Sens., Vol. 45, No. 7, pp. 2004–2018, 2007.

[43] Kimball, J.S., L.A. Jones, K. Zhang, F.A. Heinsch, K.C. McDonald, and W.C. Oechel, "A satellite approach to estimate land-atmosphere CO2 exchange for Boreal and Arctic biomes using MODIS and AMSR-E", IEEE Trans. on Geosci. Remote Sens., Vol. 47, No. 2, pp. 569-587, 2009.

[44] Zhang, K., J.S. Kimball, M. Zhao, W.C. Oechel, J. Cassano, and S.W. Running, "Sensitivity of pan-Arctic terrestrial net primary productivity simulations to daily surface meteorology

from NCEP/NCAR and ERA-40 Reanalyses", J. Geophys. Res. - Biogeosciences, Vol. 112, G01011, pp. 1–14, 2007.

[45] T. Jackson, "Soil Moisture Active Passive Validation Experiment 2008 (SMAPVEX08) Experiment Plan", September 4, 2008.

[46] WWW: Soil Moisture Active Passive Validation Experiment 2008 (SMAPVEX08), http://smap.jpl.nasa.gov/science/Validation/SMAPVEX08/

[47] R. Magagi, "Canadian Experiment for Soil Moisture 2010 (CanEx-SM10) Experiment Plan", May 28, 2010.

[48] WWW: Canadian Experiment for Soil Moisture 2010 (CanEx-SM10), http://pages.usherbrooke.ca/canexsm10/

[49] R. Panciera, "Soil Moisture Active Passive Experiments 2010-2011 (SMAPEx) Experiment Plan", June 2010.

[50] WWW: Soil Moisture Active Passive Experiments 2010-2011 (SMAPEx), http://www.smapex.monash.edu.au/

[51] T. Jackson, "San Joaquin Valley Field Campaign (UAVSAR / Soil Moisture) Experiment Plan", April 29, 2010.

[52] WWW: San Joaquin Valley Field Campaign , http://smap.jpl.nasa.gov/science/Validation/SJV/

[53] P. E. O'Neill, R. H. Lang, M. Kurum, K. R. Carver, and C. Utku, "Multisensor microwave remote sensing of NASA's combined radar/radiometer (ComRAD) system," in Proc. MicroRad'06, San Juan, Puerto Rico, pp. 50–54, Feb. 2006.

[54] M. Cosh, "SMAP In Situ Sensor Testbed Experiment Plan", United States Department of Agriculture, January 22, 2010.

[55] S. Yueh, "Estimates of Faraday Rotation with Passive Microwave Polarimetry for Microwave Remote Sensing of Earth Surfaces", IEEE Trans. Geosci. Remote Sens., Vol. 38, No. 5, September 2000.

[56] Crow, W. T., R. D. Koster, R. H. Reichle, and H. O. Sharif, "Relevance of time-varying and time-invariant retrieval error sources on the utility of spaceborne soil moisture products", Geophys. Res. Lett., Vol. 32, No. 24, Art. No. L24405, 2005.

[57] D. Entekhabi, R. H. Reichle, W. T. Crow, and R. D. Koster, Performance metrics for soil moisture retrievals and applications requirements, Journal of Hydrometeorology, in preparation, 2009.

[58] Reichle, R. H., R. D. Koster, P. Liu, S. P. P. Mahanama, E. G. Njoku, and M. Owe, "Comparison and assimilation of global soil moisture retrievals from AMSR-E and SMMR", J. Geophys. Res., Vol. 112, D09108, 2007.

[59] Bolten, J., W. T. Crow, X. Zhan, T. J. Jackson, C. A. Reynolds, "Evaluating the Utility of Remotely Sensed Soil Moisture Retrievals for Operational Agricultural Drought Monitoring", IEEE J. Selected Topics Applied Earth Obs. Remote Sens., Vol. 3, No. 1, pp. 57-66, 2010.

[60] D. Baldocchi, "Breathing of the terrestrial biosphere: lessons learned from a global network of carbon dioxide flux measurement systems", Austr. J. Bot., Vol. 56, pp. 1–26, 2008.

[61] S. R. Running, D.D. Baldocchi, D.P. Turner, S.T. Gower, P.S. Bakwin, and K.A. Hibbard, "A global terrestrial monitoring network integrating tower fluxes, flask sampling, ecosystem modeling and EOS satellite data", Remote Sensing of Environment, Vol. 70, pp. 108–128, 1999.

[62] D. Baldocchi, E. Falge, L. Gu, R. Olson, D. Holinger, S. Running, et al., "FLUXNET: A new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities", Bulletin of the American Meteorological Society, Vol. 82, pp. 2415-2434, 2001.

[63] D.P. Turner, W.D. Ritts, W.B. Cohen, S.T. Gower, S.W. Running, M. Zhao, M.H. Costa, A.A. Kirschbaum, J.M. Ham, S.R. Saleska, and D.E. Ahl., "Evaluation of MODIS NPP and

GPP products across multiple biomes", Remote Sensing of Environment, Vol. 102, pp. 282-292, 2006.

[64] W. Wilson, S. Yueh, S. Dinardo, S. Chazanoff, A. Kitiyakara, F. Li, Y. Rahmat-Samii, "Passive Active L- and S-Band (PALS) Microwave Sensor for Ocean Salinity and Soil Moisture Measurements", IEEE Trans. Geosci. Remote Sens., Vol. 39, No. 5, May 2001.

[65] S. Yueh, S. Dinardo, S. Chan, E. Njoku, T. Jackson, R. Bindlish, J. Johnson, J. Piepmeier, C. Ruf, "PALS-ADD and Airborne Campaigns to Support Soil Moisture and Sea Surface Salinity Missions", Proc. IEEE IGARSS'09, Cape Town, South-Africa, 12-17 July 2009.

[66] S. Delwart, "SMOS Validation and Retrieval Plan", http://earth.esa.int/category/index.cfm?fcategoryid=42&S_ID=39, European Space Agency, 2007.

[67] S Frolking, K. McDonald, J. Kimball, R. Zimmermann, J.B. Way and S.W. Running, "Using the space-borne NASA Scatterometer (NSCAT) to determine the frozen and thawed seasons of a boreal landscape", J. Geophys. Res., Vol. 104(D22), No. 27, pp. 895-907, 1999.

[68] WWW: SMAP Algorithms and Cal/Val Workshop, June 9-11, 2009, Oxnard, CA, USA, http://smap.jpl.nasa.gov/science/workshops/index.cfm?FuseAction=ShowNews&NewsID=18&newsTypeID=2

[69] WWW: SMAP Cal/Val Workshop #2, May 3-5, 2011, Oxnard, CA, USA, http://smap.jpl.nasa.gov/science/workshops/index.cfm?FuseAction=ShowNews&NewsID=65&newsTypeID=2

[70] J. S. Kimball, K. McDonald, A.R. Keyser, S. Frolking and S.W. Running, "Application of the NASA Scatterometer (NSCAT) for determining the daily frozen and non-frozen landscape of Alaska", Remote Sensing of Environment, Vol. 75, pp. 113–126, 2001.

[71] Kimball, J.S., K.C. McDonald, S.W. Running, and S. Frolking, "Satellite radar remote sensing of seasonal growing seasons for boreal and subalpine evergreen forests", Remote Sensing of Environment, Vol. 90, pp. 243–258, 2004.

[72] McDonald, K.C., J.S. Kimball, E. Njoku, R. Zimmermann, and M. Zhao, "Variability in springtime thaw in the terrestrial high latitudes: Monitoring a major control on the biospheric assimilation of atmospheric CO_2 with spaceborne microwave remote sensing", Earth Interactions, Vol. 8, No. 20, pp. 1–23, 2004.

Appendix A: Relevant Level 1 Science Requirements

This Appendix presents material from the SMAP L1 Science Requirements document that is relevant to the SMAP Science Calibration and Validation Program.

A.1 Scope of Level 1 Science Requirements

This appendix to the Earth Systematic Mission (ESM) Program Plan identifies the mission, science and programmatic (funding and schedule) requirements imposed on the Jet Propulsion Laboratory (JPL) for the development and operation of the Soil Moisture Active/Passive (SMAP) Project of the ESM Program. This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success following the completion of the operational phase. Program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the Earth Science Division within SMD to the ESM Program Manager at Goddard Space Flight Center (GSFC). JPL is responsible for scientific success, design, development, test, mission operations, and data verification tasks and shall coordinate the work of all contractors and science team members.

In October 2008, NASA competitively selected a SMAP Science Definition Team (SDT) that is currently planned to exist for a three-year period. The SDT provides guidance to the project on measurement requirements, product definition, algorithm development, calibration, validation, and liaison with the broader science and applications communities. NASA will competitively select a SMAP Science Team (ST) such that it will be in effect no later than one year before launch of the observatory. The ST will carry into the operations phase of the mission and support the project on calibrating and validating science data products, and liaison with the broader science and applications communities. NASA will appoint a Science Team Leader (STL) who will represent the SDT and ST to the Project and advise the Project on science issues including the science impact of potential descopes, the need for reprocessing data, and the transition of the data to a permanent archive. The SMAP Project will identify and support an application scientist to attend SMAP science team meetings, provide feedback to the SMAP science team about potential SMAP application opportunities with existing SMAP requirements, provide the Earth Science Division information about potential SMAP application opportunities, and report/publish to the application user community about potential SMAP data products and application opportunities.

Changes to information and requirements contained in this document require approval by the Science Mission Directorate (SMD), NASA Headquarters by the officials that approved the original.

A.2 Objective of SMAP Project as Defined in Level 1 Requirements

The SMAP Project will implement a spaceborne Earth observation mission designed to collect measurements of surface soil moisture and freeze/thaw state, together termed the hydrosphere state. SMAP hydrosphere state measurements will yield a critical data set that will enable science and applications users to:

- Understand processes that link the terrestrial water, energy and carbon cycles;
- Estimate global water and energy fluxes at the land surface;
- Quantify net carbon flux in boreal landscapes;
- Enhance weather and climate forecast skill;
- Develop improved flood prediction and drought monitoring capability.

To resolve hydrometeorological water and energy flux processes and extend weather and flood forecast skill, spatial resolution of 10 km and temporal resolution of 3 days are required. To resolve hydroclimatological water and energy flux processes and extend climate and drought forecast skill, spatial resolution of 40 km and temporal resolution of 3 days are required. To quantify net carbon flux in boreal landscapes spatial resolution of 3 km and temporal resolution of 2 days are required. The SMAP mission will validate a space-based measurement approach that could be used for future systematic hydrosphere state monitoring missions.

A.3 List of Relevant Requirements

Baseline Science Requirements

L1-RMS-69	a) The baseline science mission shall provide estimates of soil moisture in the top 5 cm of soil with an error of no greater than 4% volumetric (one sigma) at 10 km spatial resolution and 3-day average intervals over the global land area excluding regions of snow and ice, frozen ground, mountainous topography, open water, urban areas, and vegetation with water content greater than 5 kg m-2 (averaged over the spatial resolution scale).
L1-RMS-71	b) The baseline science mission shall provide estimates of surface binary freeze/thaw state in the region north of 45N latitude, which includes the boreal forest zone, with a classification accuracy of 80% at 3 km spatial resolution and 2-day average intervals.
L1-RMS-68	c) The baseline science mission shall collect the space-based measurements needed to retrieve estimates of soil moisture and freeze/thaw state for at least three years to enable the natural seasonal variations of soil moisture and freeze/thaw and their impacts on the surface energy, water and carbon balances to be characterized.
L1-RMS-128	d) The SMAP project shall conduct a calibration and validation program to verify data delivered meets the requirements L1-RMS-69 and L1-RMS-71.
Full Mission Success Criteria	
L1-RMS-130	* Launches into a near-polar, sun-synchronous orbit that provides near global coverage every three days. * Makes global space-based measurements of soil moisture with the accuracy, resolution, coverage, and duration to improve our understanding of the hydrologic cycle (as specified by the Baseline Science Requirements). * Records, calibrates, validates, publishes, and archives science data records and calibrated geophysical data products in a NASA Data Center for use by the scientific community (as specified in section 4.5). * Validates a space-based measurement approach and analysis concept for future systematic soil moisture monitoring missions.

Threshold Science Requirements

L1-RMS-73	a) The threshold science mission shall provide estimates of soil moisture in the top 5 cm of soil with an error no greater than 6% volumetric (one sigma) at 10 km spatial resolution and 3-day average intervals over the global land area excluding regions of snow and ice, frozen ground, mountainous topography, open water, urban areas, and vegetation with water content greater than 5 kg m-2 (averaged over the spatial resolution scale).

L1-RMS-74	b) The threshold science mission shall provide estimates of surface binary freeze/thaw state in the region north of 45N latitude which includes the boreal forest zone, with a classification accuracy of 70% at 10 km spatial resolution and 3-day average intervals.
L1-RMS-76	c) The threshold science mission shall collect the space-based measurements needed to retrieve estimates of soil moisture and freeze/thaw state for at least eighteen months in order to capture high priority seasonal periods for both soil moisture (spring and summer in the Northern Hemisphere) and freeze/thaw (spring and fall transitions).
L1-RMS-131	d) The SMAP project shall conduct a calibration and validation program to verify data delivered meets the requirements L1-RMS-73 and L1-RMS-7.
Minimum Mission Success Criteria	
L1-RMS-133	* Launches into a near-polar, sun-synchronous orbit that provides near global coverage every three days. * Makes global space-based measurements of soil moisture with the accuracy, resolution, coverage, and duration to improve our understanding of the hydrologic cycle (as specified by the Threshold Science Requirements). * Records, calibrates, validates, publishes, and archives science data records and calibrated geophysical data products in a NASA Data Center for use by the scientific community (as specified in section 4.5). * Validates a space-based measurement approach and analysis concept for future systematic soil moisture monitoring missions.

Science Instrument Requirements

L1-RMS-135	a) The SMAP instrument radiometer shall operate in the L-band frequency within the Earth Exploration Satellite Service (EESS) passive allocation of 1400 to 1427 MHz.
L1-RMS-136	b) The SMAP instrument radar shall operate in the L-band frequency EESS active allocation of 1220 to 1300 MHz.

Mission and Spacecraft Performance

L1-RMS-119	b) The SMAP mission shall complete the In-Orbit Checkout (IOC) period within 90 days after launch, and then begin operations according to the science requirements in Section 4.1
L1-RMS-137	c) The SMAP mission lifetime is 3 years baseline (18 months threshold) following completion of IOC.

Launch Requirements

L1-RMS-142	b) The SMAP observatory shall be launched into a sun-synchronous, near-polar orbit that provides near global coverage every three days.

Mission Data Requirement

L1-RMS-149	a) The SMAP Project shall produce the standard science data products listed in Table 1.
L1-RMS-146	Table 1. SMAP Data Products

<table>
<tr><td>L1-RMS-172</td><td>
<table>
<tr><th>Data Product</th><th>Description</th><th>Initial Release of Product to NASA Data Center</th><th>Subsequent data releases to NASA Data Center * (nominal)</th><th>NASA Earth Science Data Center</th></tr>
<tr><td>Level 1</td><td>Radar sensor data
Radiometer sensor data</td><td>3 months after IOC (TBC)</td><td>24 hours after receipt on the ground (TBC)</td><td>TBD</td></tr>
<tr><td>Level 2</td><td>Soil Moisture (half-orbits)</td><td>3 months after IOC (TBC)</td><td>48 hours after receipt on the ground (TBC)</td><td>TBD</td></tr>
<tr><td>Level 3</td><td>Freeze/Thaw (>45°N)
Soil Moisture (global)</td><td>6 months after IOC (TBC)</td><td>72 hours after receipt on the ground (TBC)</td><td>TBD</td></tr>
</table>
* After the initial release to the NASA Data Center</td></tr>
<tr><td>L1-RMS-147</td><td>b) All data and standard products shall be delivered, in accordance with the NASA Earth Science Data and Information Policy specified in the 2006 Earth Science Reference Handbook (NP-2006-5-768-GSFC), to a NASA SMD Earth Science Division-assigned Data Center. Public release of this data shall conform to the NASA Earth Science Data and Information Policy, U.S. Law, and the NASA/CalTech prime contract (NAS7-03001).</td></tr>
<tr><td>L1-RMS-151</td><td>c) The project shall deliver to the assigned data center all data and products (see Table 1).</td></tr>
<tr><td>L1-RMS-152</td><td>d) Science algorithms used to generate the data products listed in Table 1 shall be documented in Algorithm Theoretical Basis Documents (ATBDs).</td></tr>
<tr><td>L1-RMS-154</td><td>a) SMAP’s science data product formats shall conform to the Hierarchical Data Format (HDF5) standard.</td></tr>
<tr><td>L1-RMS-155</td><td>b) The SMAP science data products metadata shall conform to ISO 19115 “Geographic Information - Metadata” and the ISO 19115 “North American Profile”.</td></tr>
<tr><td>L1-RMS-156</td><td>c) The SMAP Project shall coordinate with the Earth Science Data Center the release of product versions, to ensure completeness and accuracy of quality information and validation status of the SMAP science data products.</td></tr>
<tr><td>L1-RMS-158</td><td>Beginning in Phase C, the SMAP Project shall organize and host a SMAP data product application workshop annually. The workshop will share information on SMAP science data applications and define potential applications that can be supported with existing SMAP data requirements. Results will be provided to the SMAP science team and at other SMAP workshops and meetings.</td></tr>
</table>

Appendix B: Relevant Level 2 Science Requirements

This Appendix presents a selection of the contents of SMAP L2 Science Requirements document that is relevant to the SMAP Science Calibration and Validation Program.

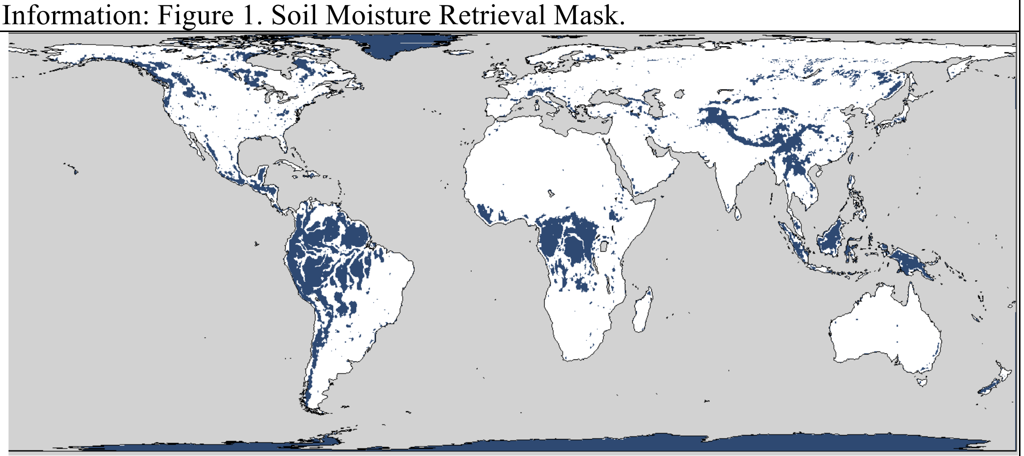
B.1 Scope of Level 2 Science Requirements

SMAP is a NASA Tier-1 Earth Science Decadal Survey mission. This document provides the science requirements for the mission, derived from the overall mission objectives and program level constraints. It responds to the SMAP Level 1 Requirements and Mission Success Criteria.

B.2 List of Relevant Requirements

Science Data Products

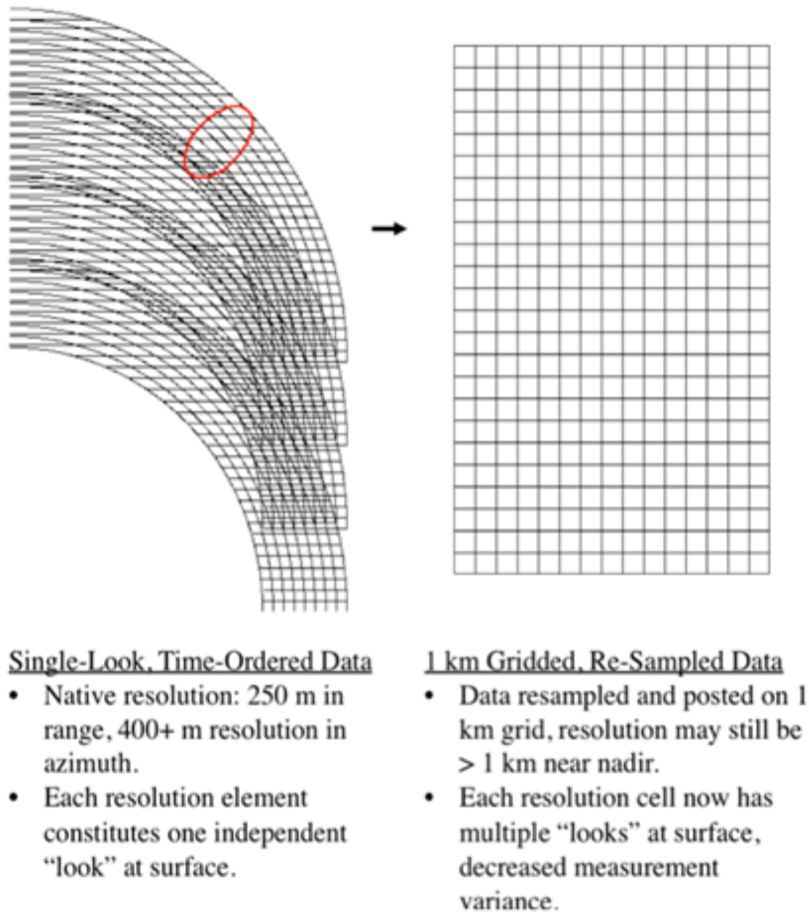
<table>
<tr><td>L2-SR-300</td><td>Information: Definitions of the SMAP data product levels are provided in Table 2.</td></tr>
<tr><td>L2-SR-315</td><td>
<table>
<tr><th>Data Product Level</th><th>Description</th></tr>
<tr><td>Level 0</td><td>Reconstructed, unprocessed instrument data at original resolution, time ordered, all communications artifacts removed</td></tr>
<tr><td>Level 1A</td><td>Level 0 data time referenced and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (i.e., platform ephemeris) computed and appended, but not applied to Level 0 data</td></tr>
<tr><td>Level 1B</td><td>Radiometrically corrected and geolocated Level 1A data that have been processed to sensor units</td></tr>
<tr><td>Level 1C</td><td>Level 1B data that have been spatially resampled</td></tr>
<tr><td>Level 2</td><td>Derived geophysical parameters at the same resolution and location as the Level 1 data from which they are derived</td></tr>
<tr><td>Level 3</td><td>Geophysical parameters derived from Level 1 or 2 data that have been spatially and/or temporally re-sampled to a global grid</td></tr>
<tr><td>Level 4</td><td>Geophysical parameters derived by assimilating Level 1, 2, or 3 data into a land surface model</td></tr>
</table>
</td></tr>
<tr><td>L2-SR-259</td><td>The SMAP data products, the algorithms used to produce them, and the error budget allocations shall be described in Algorithm Theoretical Basis Documents (ATBDs) for each product.</td></tr>
<tr><td>L2-SR-368</td><td>The SMAP Level 1 and Level 2 data products shall be generated in half-orbit granules, starting and ending at the poles.</td></tr>
<tr><td>L2-SR-344</td><td>SMAP shall provide a Level 1A time-ordered radar data product (L1A_Radar).</td></tr>
<tr><td>L2-SR-345</td><td>SMAP shall provide a Level 1A time-ordered radiometer data product (L1A_Radiometer).</td></tr>
<tr><td>L2-SR-266</td><td>SMAP shall provide a Level 1B time-ordered radar sigma-0 product (L1B_S0_LoRes) at 30 km spatial resolution.</td></tr>
<tr><td>L2-SR-268</td><td>SMAP shall provide a Level 1B time-ordered radiometer brightness temperature product (L1B_TB) at 40 km spatial resolution.</td></tr>
<tr><td>L2-SR-265</td><td>SMAP shall provide a Level 1C radar sigma-0 product (L1C_S0_HiRes) at less than or equal to 3 km spatial resolution on a 1-km grid.</td></tr>
<tr><td>L2-SR-267</td><td>SMAP shall provide a Level 1C radiometer brightness temperature product (L1C_TB) at 40 km spatial resolution on a 36-km grid.</td></tr>
</table>

L2-SR-370	The Level 2-4 science data products shall be generated on a set of nested grids that are defined in Science Document #033 "SMAP Fixed Earth Grids" (Docushare collection 56076).
L2-SR-346	SMAP shall provide a Level 2 data product (L2_SM_A) at 3 km spatial resolution representing the average soil moisture in the top 5 cm of soil.
L2-SR-347	SMAP shall provide a Level 2 data product (L2_SM_P) at 40 km spatial resolution representing the average soil moisture in the top 5 cm of soil.
L2-SR-348	SMAP shall provide a Level 2 data product (L2_SM_A/P) at 10 km spatial resolution representing the average soil moisture in the top 5 cm of soil.
L2-SR-371	SMAP Level 3 data products shall be generated by compositing Level 1 and Level 2 data products over a 1-day period onto global grids.
L2-SR-260	SMAP shall provide a Level 3 data product (L3_F/T_A) at 3 km spatial resolution representing the binary surface freeze/thaw state.
L2-SR-263	SMAP shall provide a Level 3 data product (L3_SM_A) at 3 km spatial resolution representing the average soil moisture in the top 5 cm of soil.
L2-SR-262	SMAP shall provide a Level 3 data product (L3_SM_P) at 40 km spatial resolution representing the average soil moisture in the top 5 cm of soil.
L2-SR-261	SMAP shall provide a Level 3 data product (L3_SM_A/P) at 10 km spatial resolution representing the average soil moisture in the top 5 cm of soil.
L2-SR-264	SMAP shall provide a Level 4 soil moisture data assimilation product (L4_SM).
L2-SR-331	SMAP shall provide a Level 4 carbon net ecosystem exchange data assimilation product (L4_C).
L2-SR-301	The Level 2 soil moisture 10 km data (L2_SM_A/P) shall have error no greater than 0.04 cm3/cm3 (1-sigma) averaged over the land area specified by the "Soil Moisture Retrieval Mask" in Figure 1 (white areas).
L2-SR-349	Information: Figure 1. Soil Moisture Retrieval Mask.
L2-SR-358	
L2-SR-269	The Level 3 freeze/thaw 3 km data (L3_F/T_A) shall have classification accuracy no less than 80% averaged over the land area specified by the "Boreal Freeze/Thaw Retrieval Mask" in Figure 2.
L2-SR-350	Information: Figure 2. Boreal Freeze/Thaw Retrieval Mask (land region above 45 degrees north).

L2-SR-359	

Instruments

L2-SR-33	The SMAP radiometer shall operate in the L-band frequency range allocated for passive remote sensing (1400-1427 MHz).
L2-SR-35	The SMAP radar shall operate in the L-band frequency range allocated for active remote sensing (1215-1300 MHz).
L2-SR-34	The SMAP radiometer shall measure H, V, and 3rd and 4th Stokes parameter brightness temperatures.
L2-SR-36	The SMAP radar shall measure co-polarized horizontal (HH), co-polarized vertical (VV), and cross-polarized (HV) backscatter cross-sections.
L2-SR-37	The antenna beam incidence angle shall have a nominally constant value across the swath, chosen to be between 35 and 50 degrees, for the entire mission duration.
L2-SR-38	The antenna beam incidence angle shall be controlled to within 1 degree (3-sigma).
L2-SR-39	The antenna beam incidence angle shall be known to within 0.2 degrees (3-sigma).
L2-SR-40	The radiometer and radar (real aperture) antenna beams shall be co-boresighted to within 0.2 degrees (3-sigma).
L2-SR-41	The radiometer spatial resolution for all channels shall be equal to or less than 40 km.
L2-SR-42	Adjacent radiometer EFOVs shall overlap by a minimum of 30% in both elevation (cross-scan) and azimuth (along-scan).
L2-SR-302	The real-aperture (Lo-Res) radar spatial resolution for all channels shall be 30 km or better.
L2-SR-373	SAR-processed single-look measurement samples shall be averaged (multi-looked) onto 1-km grid pixels to form the L1C_S0_HiRes data product (Figure 4).

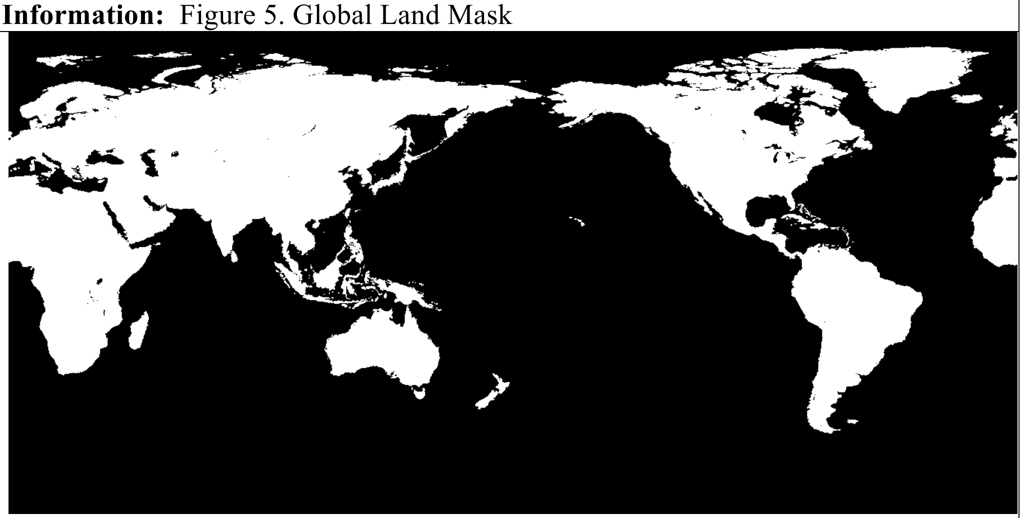
<table>
<tr><td>L2-SR-374</td><td>Information: Figure 4: Schematic diagram illustrating averaging of SAR single-look samples (time-ordered) onto 1-km grid to form the L1C_S0_HiRes product. The grid posting of the L1C_S0_HiRes product is fixed at 1 km but the spatial resolution varies across the swath.

</td></tr>
<tr><td>L2-SR-44</td><td>All L1C_S0_HiRes 1-km grid pixels shall contain multi-looked SAR data (no empty pixels).</td></tr>
<tr><td>L2-SR-43</td><td>The spatial resolution of the L1C_S0_HiRes data shall be equal to or less than 3 km over at least 70% of the swath.</td></tr>
</table>

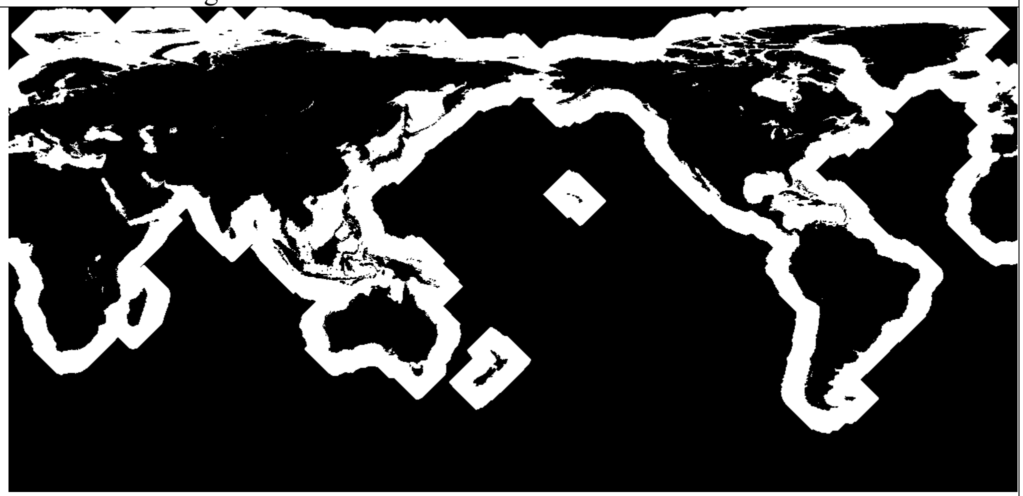
Instrument Measurement Errors

L2-SR-295	Radiometer Level 1B Processing shall include compensation for effects of antenna side lobes (outside the radiometer antenna main beam), cross-polarization, Faraday rotation, atmospheric effects (excluding rain), and solar, galactic and cosmic radiation.
L2-SR-45	The L1B_TB brightness temperatures shall have mean uncertainty from all sources (excluding rain) of 1.3 K or less (1-sigma) in the H and V channels, computed by binning fore- and aft-look samples into 30 km x 30 km grid cells.
L2-SR-47	The radiometer footprints shall have geolocation knowledge uncertainty (3-sigma) of less than 4 km.
L2-SR-375	Radar L1C_S0_HiRes processing shall include terrain-corrected geolocation and corrections for ionospheric and atmospheric effects (excluding rain).

L2-SR-46	The L1C_S0_HiRes HH and VV data shall have uncertainty from all sources (excluding rain) of 1.0 dB or less (1-sigma) defined at 3 km spatial resolution and for surfaces of radar cross-section greater than -25 dB.
L2-SR-376	The L1C_S0_HiRes HV data shall have uncertainty from all sources (excluding rain) of 1.5 dB or less (1-sigma) defined at 3 km spatial resolution and for surfaces of HV radar cross-section greater than -30 dB.
L2-SR-48	The radar Hi-Res pixels shall have geolocation knowledge uncertainty (3-sigma) of less than 1 km.

Data Acquisition

L2-SR-49	Radiometer data shall be acquired continuously over fore and aft portions of the scan (full 360 degrees) and ascending and descending portions of the orbit.
L2-SR-50	Low resolution (Lo-Res) radar data shall be acquired continuously over fore and aft portions of the scan (full 360 degrees) and ascending and descending portions of the orbit.
L2-SR-51	High resolution (Hi-Res) radar data shall be acquired to include at a minimum: (a) 360 degrees of the antenna scan (fore and aft looks) for the AM (6-AM Equator crossing) half-orbit over the "Global Land" region; (b) 180 degrees of the antenna scan (fore look) for the PM (6-PM Equator crossing) half- orbit over the "Boreal Land" region; (c) 180 degrees of the antenna scan (fore look) for the AM half-orbit over the "Coastal" region. Mask files are provided to define these regions (shown in Figures 5, 6, and 7).
L2-SR-355	**Information:** Figure 5. Global Land Mask
L2-SR-360	
L2-SR-356	**Information:** Figure 6. Boreal Land Mask
L2-SR-361	

L2-SR-357	**Information:** Figure 7. Coastal Ocean Mask
L2-SR-362	
L2-SR-52	The SMAP science orbit shall have a ground track that crosses the Equator at 6 am (within plus or minus 30 minutes) and 6 pm (within plus or minus 30 minutes) local solar time.
L2-SR-54	The science orbit shall be an 8-day exact repeat fixed reference trajectory, maintained to within +/- 20 km of the reference trajectory.
L2-SR-55	Level 1 science data shall be provided with less than 12% data loss from all causes, computed monthly and averaged over the mission, defined separately for radar and radiometer data streams and relative to the mask specified in L2-SR-301.

Data Processing and Delivery

L2-SR-56	Level 1 data products shall be made available to the Science Team by the SDS within a mean latency of less than 12 hours (computed monthly) of the corresponding data acquisition by the observatory under normal operating conditions.
L2-SR-324	Level 2 data products shall be made available to the Science Team by the SDS within a mean latency of less than 24 hours (computed monthly) of the corresponding data acquisition by the observatory under normal operating conditions.
L2-SR-353	Level 3 data products shall be made available to the Science Team by the SDS within a mean latency of less than 50 hours (computed monthly) of the corresponding data acquisition by the observatory under normal operating conditions.
L2-SR-325	The Level 4 soil moisture data assimilation product shall be made available to the Science Team by the SDS within a mean latency of less than 7 days (computed monthly) of the corresponding data acquisition by the observatory under normal operating conditions.
L2-SR-342	The Level 4 carbon (net ecosystem exchange) data assimilation product shall be made available to the Science Team within a mean latency of 14 days of the corresponding data acquisition by the observatory under normal operating conditions.
L2-SR-57	Ancillary data shall be acquired by the Science Data System (SDS) as necessary to meet the accuracy and latency requirements of the science products.

L2-SR-383	All science data products made available to the designated Data Center for public release shall be assigned an algorithm version number and a data quality designation of beta, provisional or validated as approved by the Science Team.
L2-SR-384	User guide documentation shall be provided along with the science data products made available to the Data Center for public release.
L2-SR-385	Within three months (TBC) after start of the SOP, Level 1 data products (beta or provisional) shall be made available to the Data Center for initial public release.
L2-SR-386	Within three months (TBC) after start of the SOP, Level 2 data products (beta or provisional) shall be made available to the Data Center for initial public release.
L2-SR-387	Within six months (TBC) after start of the SOP, Level 3 data products (beta or provisional) shall be made available to the Data Center for initial public release.
L2-SR-326	Within six months after start of the SOP, validated Level 1 data products shall be made available to the Data Center for public release.
L2-SR-327	Within twelve months after start of the SOP, validated Levels 2-4 data products shall be made available to the Data Center for public release.
L2-SR-328	After science data products have been made available to the Data Center for initial public release, subsequent availability of those products to the Data Center shall be with the same latency (TBC) as provided by the SDS to the Science Team.
L2-SR-58	The cumulative mission science data shall be reprocessed a minimum of three times (TBC) to implement upgrades in processing algorithms and improve archived data product quality.
L2-SR-82	The final processed 3-year mission data set shall be made available to the Data Center within one month after the end of the 3-year Science Operations Phase (SOP).
L2-SR-388	The SMAP project shall conduct a calibration and validation (Cal/Val) program: (a) Pre-launch, to ensure the development of robust science algorithms, and (b) Post-launch, to verify and characterize the accuracies of the delivered science data products (listed in Table 1).
L2-SR-389	A SMAP Calibration and Validation Plan shall be provided describing the pre- and post-launch activities conducted under the Cal/Val program.
L2-SR-329	Cal/Val reports describing the calibration, validation and error characteristics of the SMAP science data products shall be generated and provided to the Data Center along with the science data products, including an Interim Report within three months of the end of the Cal/Val Phase and a Final Report within 3 months of the end of the 3-year science mission.

Appendix C: Supporting Instrumentation for Cal/Val

This Appendix describes some airborne and ground-based instruments which may play a key role in SMAP Calibration and Validation Program in both pre- and post-launch phases

C.1 PALS

The PALS (Passive and Active L- and S-band) instrument is an airborne L-band radiometer which includes both radiometer and radar operating both at L- and S-band. The instrument has been deployed on different platforms including C-130 and Twin Otter aircrafts. The nominal viewing angle of the instrument is 40° [64]. The most recent configuration with a light-weight relative small-size microstrip antenna has been deployed on Twin Otter, see Figure C-1.

Figure C-1. Twin Otter (on the left-hand side) and light-weight relative small-size microstrip antenna (on the right-hand side)

The PALS have been utilized for soil moisture field experiment multiple times in the past. These campaigns included SGP99 in Oklahoma in 1999; SMEX02 in Iowa in 2002; CLASIC in Oklahoma in 2007, and SMAPVEX08 in Maryland in 2008. The configuration of the instrument changed from campaign to campaign, but the performance parameters remained the same throughout all campaigns. Table C-1 summarizes the performance parameters. In SGP99 and SMEX02 PALS flew on a C-130 aircraft operated by NCAR. In CLASIC and SMAPVEX08 (see Section 5.5.2.1) it flew on a Twin Otter (DHC-6) aircraft. In SGP99 and SMEX02 PALS was using a horn antenna with 13° beamwidth, but in CLASIC and SMAPVEX08 the next generation design incorporated a lightweight microstrip antenna (which allowed the installation to the Twin Otter) with 20° beamwidth. Additionally, in SMAPVEX08 PALS was flown with an Agile Digital Detector (ADD) for RFI mitigation [65].

In order to facilitate cost-effective characterization of large spatial domains for Cal/Val, the SMAP Cal/Val Working Group and the SDT recommended that the sensor be modified to include scanning. This effort was initiated and should be completed in the near future.

Table C-1. Characteristics of PALS instrument (different antenna configurations have been deployed for different campaigns).

Passive	Frequency	1.413 GHz
	Polarization	V, H, +45, -45
	Calibration stability	1 K (bias); 0.2 K (stability)
Active	Frequency	1.26 GHz
	Polarization	VV, HH, VH, HV
	Calibration accuracy	<2 dB (bias); 0.2 dB (stability)
Antenna (SGP99, SMEX02)	Half Power Beamwidth	12° (passive); 13° (active)
	Beam efficiency	92%
	Directivity	23.4 dB
	Polarization isolation	>20 dB
Antenna (CLASIC, SMAPVEX08)	Half Power Beamwidth	20° (passive); 23° (active)
	Beam Efficiency	94%
	Directivity	18.5 dB
	Polarization isolation	> 35 dB

C.2 UAVSAR

The UAVSAR instrument is a reconfigurable, polarimetric L-band synthetic aperture radar (SAR) specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements. The radar was designed to be operable on a UAV (Uninhabited Aerial Vehicle), but it is currently implemented on a NASA Gulfstream III. Figure C-2 shows a photo of the Gulfstream III aircraft with the UAVSAR instrument installed in the belly pod.

Figure C-2. The UAVSAR instrument in the belly pod of NASA Gulfstream III aircraft.

The radar is fully polarimetric, with a range bandwidth of 80 MHz, and will support a ~20 km range swath, which translates to an incidence angle range of 25°-65°. The system operates nominally at 45,000 ft (13800 m). Using precision real-time GPS and a sensor controlled flight management system the system will be able to fly predefined paths with great precision. The performance of the flight control system requires the flight path to be within a 10 m diameter tube about the desired flight track. The accuracy of the measured radar cross-section is 1 dB without calibration targets (corner reflectors) in the vicinity of the experiment area and 0.1 dB with calibration targets. Table C-2 summarizes the relevant parameters of the UAVSAR instrument.

Table C-2. Relevant parameters of the UAVSAR instrument.

Parameter	Value
Frequency	L-band (1.26 GHz)
Bandwidth	80 MHz
Resolution, Range	1.8 m
Resolution, Azimuth	0.6 m
Resolution, Product	6 m
Accuracy	1 dB / 0.1 dB
Polarization	Full Quad-Polarization
Antenna Type	Phased Array
Antenna Dimensions	0.5 m range/1.5 azimuth
Polarization Isolation	<-20 dB
Waveform	Nominal Chirp/Arbitrary Waveform
Swath	25° - 65° off nadir

C.3 ComRAD

The ComRAD instrument is a truck-mounted L-band radiometer and radar developed by NASA Goddard Space Flight Center and George Washington University, see Figure C-3 [53]. The instrument utilizes a parabolic dish antenna for both passive and active measurements. The mounting allows wide scanning in both elevation and azimuth directions and measurements from height of about 20 m. Table C-3 shows some characteristic parameters of the ComRAD instrument.

Figure C-3. ComRAD.

Table C-3. Parameters of ComRAD.

Passive	Frequency	1.413 GHz
	Polarization	V, H
	Accuracy	1 K
Active	Frequency	1.25 GHz
	Polarization	VV, HH, VH, HV
	Accuracy	?
Antenna	Half Power Beamwidth	12° (passive); 13° (active)
	Gain	19.5 dB
	Polarization isolation	~20 dB

The Cal/Val Working Group and SDT suggested that modifications of ComRAD would be needed in order to collect the type of data needed for algorithm development and validation. Key requirements were the ability to operate autonomously over extended periods of time and improving the reliability of the radiometer calibration. As a result, the ComRAD team initiated system improvements, including a new antenna. These are expected to be completed by the Spring/Summer of 2011.

Appendix D: Field Experiments of Opportunity

This Appendix describes field campaigns planned outside SMAP domain that may, however, provide opportunity for acquiring valuable data from SMAP science calibration and validation point of view. At this time, some of the recent selections under the NASA ESSP Venture-class Science Investigations Program may have positive or negative impacts of the SMAP Cal/Val Plan. Details of these projects are being developed and the SMAP Cal/Val Working Group will be looking for opportunities to exploit these.

D.1 CARVE

The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) is designed to understanding of Arctic ecosystems, linkages between the Arctic hydrologic and terrestrial carbon cycles, and the feedbacks from fires and thawing permafrost. The PI is Charles Miller. The key mission parameters are:

Aircraft	Twin Otter
Instruments	Passive-Active L-band (PALS), FTS, ISGA
Region	Alaska (Fairbanks base of operation)
Mission	Conduct three a year over fixed flight lines each year 2011-2015. Flights will take place in mid April (not in 2011), June and August. Each will require about 2 weeks. Between flights, the instruments and aircraft will be left in Fairbanks (without a crew). The aircraft would be available in each of these 6 week periods.
Flight Lines	Set, waiting on details (see Figure D-4)
Other	Need resolution of time line and flight lines

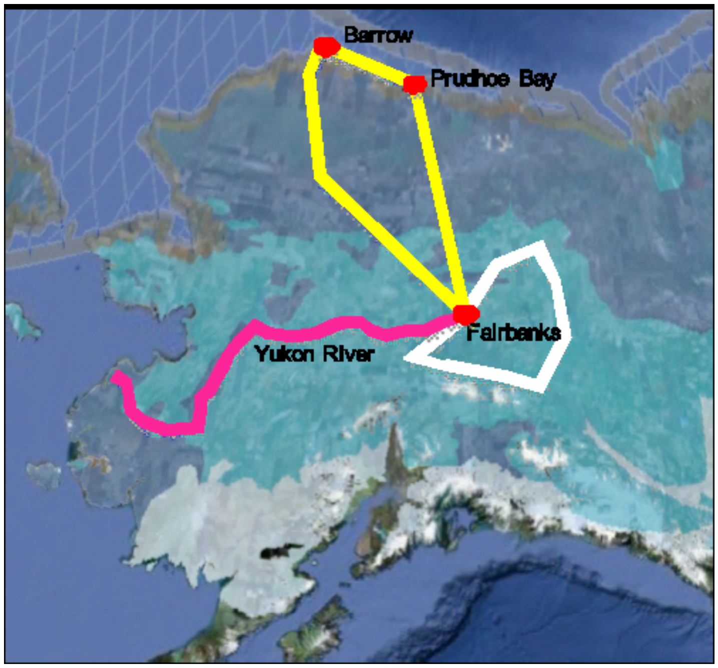


Figure D-4. CARVE flight plans. Colors indicate continuous (dark blue), discontinuous (light blue), sporadic (gray), and subsea (hatched) permafrost regimes. Each colored loop represents a single day's flight path. The gold flight path is anchored by flights over 5 flux towers which will be used for validation. (Provided by S. Dinardo)

D.2 AirMOSS

Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) Mahta Moghaddam (PI, UofM). Addresses key questions: 1. How does root zone soil moisture, and its landscape heterogeneity, control the regional carbon fluxes? 2. How is this control quantified via estimates of root zone soil moisture at spatial (100-1000m) and temporal (daily to weekly) sampling?

Aircraft	NASA G-III
Instruments	Polarimetric UHF synthetic aperture radar, 280-440 MHz band capability, 80 MHz total bandwidth (capability for both split spectrum and contiguous). Radar to fit inside a G-3 pod
Region	Survey major biomes in North America
Mission	Visit 9 flux tower sites, three times for temperate & boreal sites, twice for arid/semiarid, once for tropical sites; each time complete 3 surveys over 7-10days. 3 seasons (depends) over 3 years; Mid-March to Mid-April; Mid-June to Mid-July, and first 2 weeks of October.
Flight Lines	Set, waiting on details (see Figure D-5)
Other	Updated estimates indicate that the instrument will be ready for June 2012. Sites may change.

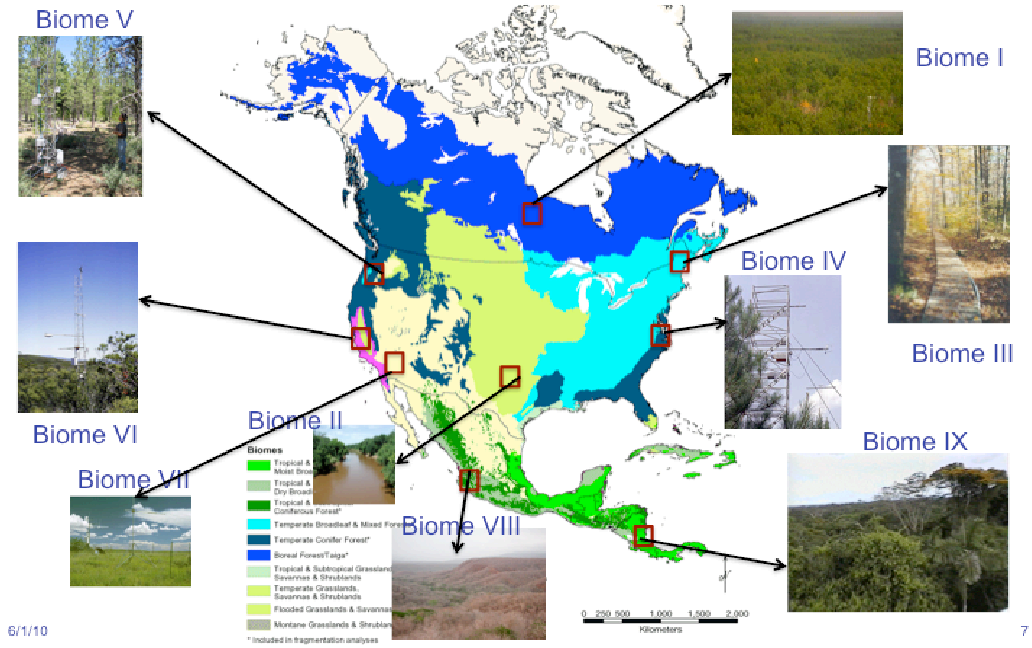


Figure D-5. AirMOSS study sites. (Provided by M. Moghaddam).

Appendix E: Cal/Val Programs of Other Soil Moisture Missions

There are other soil moisture missions in operation or in development during the SMAP pre- and post-launch phases (see Section 3.3.4). This Appendix highlights the key features of the cal/val programs of European Space Agency's (ESA) SMOS mission, Japan Aerospace Exploration Agency's (JAXA) GCOM-W mission, and Argentinean Space Agency's (CONAE) SAOCOM mission.

E.1 SMOS Soil Moisture Cal/Val Program

SMOS (Soil Moisture and Ocean Salinity) is European Space Agency's Earth observation satellite mission focused on measurement of soil moisture sea surface salinity utilizing L-band radiometry. The resolution of the soil moisture product of the mission is about 40 km and the revisit time 2-3 days. The performance requirement of 0.04 cm^3/cm^3 coincides with that of SMAP. SMOS will measure each pixel at multiple incidence angles and this multi-incidence angle information will be exploited to retrieve soil moisture and other geophysical variables.

The SMOS Validation and Retrieval Team (SVRT) Plan was developed from the responses to the call for proposals to conduct calibration and validation activities for SMOS [66]. Following the SMOS AO Review Panel Meeting held in ESA ESTEC 9-10 June 2005, 39 proposals were accepted on the basis of their potential contribution for calibrating and validating SMOS products. These proposals form the basis of the SVRT Plan. Activities included in situ soil moisture measurement, ground- and aircraft-based microwave radiometer measurements, satellite inter-comparisons, and model products.

Figure E-1 provides the locations of the selected validation sites.

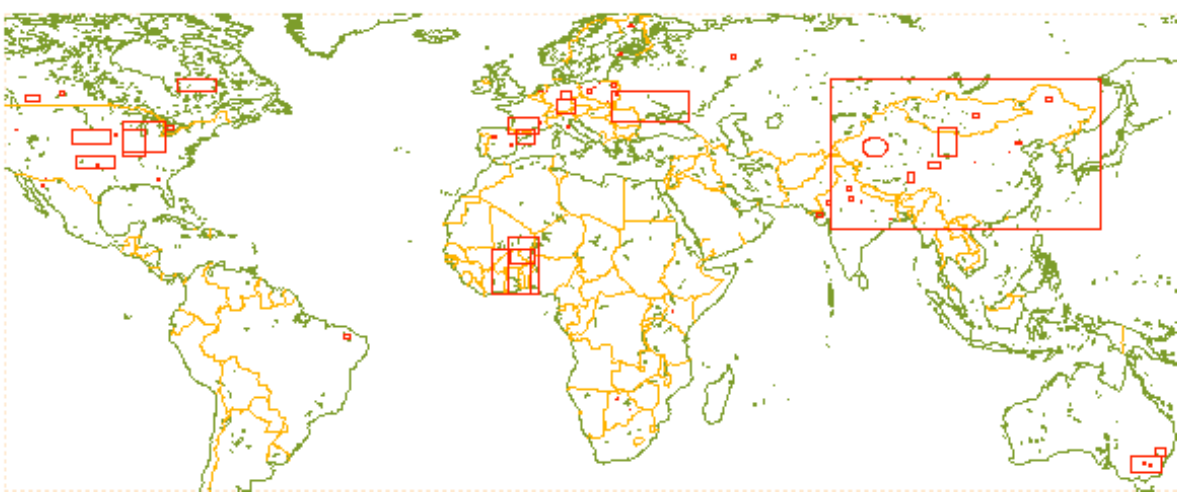


Figure E-1. Locations of SMOS soil moisture validation sites.

The SVRT plan recommended measurement protocols for the soil moisture validation sites that included being at least 100 km away from any coastline. The validation sites are responsible for up-scaling observations and for being compliant with the measurement protocols.

In addition to the sites selected through this process, SMOS supports several "anchor" sites. These sites in Spain, Germany, and Australia were designed to provide much more extensive ground based observations including multiple sites within a SMOS footprint. Airborne campaigns were conducted over these sites prior to launch to characterize both the radiometric and geophysical variables and post-launch campaigns will also be conducted.

In order to support both the satellite instrument calibration, site scaling, and algorithm refinement the SMOS mission developed ground- and aircraft-based L-band radiometers that will be deployed at the anchor sites as well as other sites selected through a competitive process.

In order to provide an accessible long term resource to support the analysis of SMOS products and those from future sensors, datasets comprising SMOS products and correlative data from in-situ or models are held within a dedicated SMOS cal/val campaign database.

SMOS SVRT is ongoing and SMAP project and SDT members actively participate. The SMAP project will maintain these relationships and expand them as needed.

E.2 AMSR-2 Soil Moisture Cal/Val Program

JAXA will support the Cal/Val of its GCOM-W AMSR-2 program using sites that it supports in Asia and from proposals submitted to announcements of opportunities. The validation sites are typically well characterized and provide data in regions of the world that complement the core activities of NASA and ESA missions. Some of these such as the Mongolia site have long-term observations initiated for AMSR and AMSR-E.

Members of the SMAP SDT currently participate in the AMSR-2 Cal/Val program and will continue this effort. The SMAP project will establish agreements with JAXA/GCOM-W as needed to facilitate the exchange of data for Cal/Val.

E.3 SAOCOM Soil Moisture Cal/Val Program

As part of its SAOCOM program, CONAE will provide a high resolution validated soil moisture product from L-band radar backscatter. Both the backscatter measurements and soil moisture will be of value to SMAP Cal/Val. CONAE is currently supporting projects to validate soil moisture from Aquarius. They plan to establish in situ validation sites for SAOCOM; however, details are not available at this time. CONAE has also developed an aircraft-based L-band SAR that will support pre-launch algorithm development and post-launch validation.

The SMAP project and SDT have submitted a proposal to the CONAE SAOCOM announcement of Opportunity for pre-launch collaboration and will extend this in the follow on announcements.